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MASTER'S THESIS

Performance analysis of the movement patterns and technical demands of international women's rugby sevens preparation training camps

Griffin, Jesse

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Performance Analysis of the Movement Patterns and Technical Demands of International Women's Rugby Sevens Preparation Training Camps

Jesse Alexander Griffin

Bachelor of Sport Coaching and Exercise Science, University of Canberra

A thesis submitted to Bond University
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Bond University

Abstract

Rugby sevens has now been introduced as an Olympic sport at the 2016 Olympic Games in Rio de Janeiro, Brazil. Despite inclusion as an Olympic sport, there is limited research investigating rugby sevens matches with even less known about the current training practices of international rugby sevens teams. The two studies of the present thesis aim to address the imbalance of research between matches and training practices, by quantifying the movement patterns of training camps and the effect of defensive pressure on the frequency and execution of key attacking skills.

Study one included twenty four international women's rugby sevens players (age 24 ± 5 years, height 168 ± 5 cm, body mass 68 ± 6 kg; mean \pm SD) that were monitored over seven training camps during the 2012 – 2013 international season. Global Positioning System (GPS) units with integrated triaxial accelerometers were used to quantify the movement patterns of the training camps. Women's rugby sevens players covered a median (interquartile range (IQR)) total distance of 3823 (3126 – 4398) m or a relative distance of 2655 (2267 – 3030) m/hour during training camp sessions that lasted a total of 91 (76 – 98) minutes. Women's rugby sevens players also experienced a training load of 389 (295 – 562) arbitrary units (AU) and a relative load of 300 (240 – 360) AU/hour. Total distance consisted of 179 m (119 – 253) or 126 m/hour (83 – 168) of high-intensity running (HIR) and 50 m (24 – 88) or 35 m/hour (18 – 58) of sprinting. One hundred and twenty five (97 – 149) accelerations occurred during a training sessions with 86 (70 – 103) accelerations occurring per hour. Sprints occurred 41 (29 – 53) times and repeated sprints occurred 14 (8 – 21) times during training camp sessions at a rate of 28 (21 – 36) sprints per hour and 10 (6 – 15) repeated sprints per hour. A significant large effect size decrease was observed for the absolute training load, total distance, accelerations, decelerations, sprints and repeated sprints from session 3 to 4. A significant large effect size increase was observed for the relative training load, accelerations, sprints and repeated sprints from session 2 to 3. Coaches need to monitor the interaction that occurs between the physical, technical and tactical demands to ensure training sessions are maintaining or improving the physiological adaptations. To address specificity of training the physical demands during training sessions need to include periods that better match the duration and intensity of rugby sevens matches with coaches mindful of intermittent breaks during drills.

Study two utilised a notational analysis approach to examine the effect of defensive pressure during game-based drills. The analyses was conducted on 42 preparation training camp drills during the 2012 – 2013 international season. All analyses of training sessions occurred in lapsed time with the skill execution outcomes assessed including pass type, pass accuracy, catching, evasive moves and line breaks. Defensive pressure had a significant effect on pass type, evasive moves and line breaks ($p < 0.05$), however there was no significant effect on passing accuracy and the catching ability of players ($p > 0.05$). A cut-out pass (standard residual (SR) = 3.3) and a switch pass (SR = 3.7) were more likely to happen than expected by chance during no defence and uncontested defence respectively. An offload was more likely to happen than expected by chance during contested defence (SR = 9.6). No defence had the most accurate passing with 60% good accuracy compared to 55% during contested defence. A line break (SR = 4.7) and a swerve (SR = 2.5) were more likely to happen than expected by chance during contested defence. Coaches may need to structure annual training programs and individual training sessions to progressively overload the technical and tactical skills in order for the technical and decision making skills to develop and transfer to match performance. The interaction between the physical, technical and tactical demands should also be monitored in order to understand and control these interactions for the desired training outcome.

The present thesis provides insight into preparation training camps that may better allow coaches to improve the transfer of training performance to tournament success in rugby sevens for all aspects of preparation. The results from study one demonstrate that as a result of training sessions focusing on the technical and tactical skills and developing team cohesion, training sessions when considered as a whole may be insufficient to maintain or enhance physiological adaptations. While the coaching staff need to utilise training camps to develop the technical and tactical skills of players, the interaction between the physical, technical and tactical demands may need to be monitored in order to balance these interactions for the desired training outcome. Sufficient exposure to match-like conditions, such as those involving contested defensive pressure should better enable technical skill development and physical conditioning to be developed and transferred to match performance. Progressing too quickly or providing insufficient exposure to match-like conditions can however, lead to acute decrements in skill frequency and execution that may impair skill acquisition, while also potentially causing detraining of players physical conditioning over long term periods. Collectively, the results of the two studies suggest that quantifying current training practices is essential in preparing players for the physical,

technical and tactical demands of matches, so that a transfer of the benefits gained during training is evident in match performance.

Declaration

The present thesis is submitted to Bond University in fulfilment of the requirements for the degree of Master of Science by Research. The present thesis represents my own original work towards a Master's degree and contains no material which has been previously submitted for a degree or diploma at Bond University or any other institution, except where due acknowledgement is made.

Signed: _____

Jesse A. Griffin

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Table of Contents

Abstract	ii
Declaration	vi
Copyright Declaration.....	viii
Acknowledgements	x
Table of Contents.....	xii
Conference Proceedings	xvi
List of Figures	xviii
List of Tables.....	xx
Abbreviations	xxii
Units of Measurement.....	xxiv
Chapter One: Introduction.....	1
Rugby Sevens	1
Project Aims	6
Chapter Two: Literature Review.....	7
Introduction	7
Search Strategies.....	7
Global Positioning System Definitions and Thresholds Used in the Rugby Sevens	
Literature	8
Rugby Sevens	16
Physical Demands of Rugby Sevens Matches	16
Technical Demands of Rugby Sevens Matches	32
Epidemiology of Injury in Rugby Sevens	34
Conclusion	38
Performance Analysis of Sporting Performance	38
Validity and Reliability of Global Positioning System (GPS) Units.....	42
Introduction to GPS Units.....	42
Validity of GPS Units.....	48

Reliability of GPS Units	52
Notational Analysis of Technical and Tactical Skills.....	52
Notational Analysis of Rugby Sevens.....	54
Conclusion	55
Chapter Three: Quantifying the Movement Patterns of International Women's Rugby	
Sevens Preparation Training Camp Sessions	57
Abstract	57
Introduction	58
Methods	59
Experimental Approach to the Problem.....	59
Subjects.....	60
Training Camps	63
Global Positioning System	63
Session Rating of Perceived Exertion and Training Load.....	64
Statistical Analysis	64
Results	65
Discussion.....	71
Conclusion	74
Chapter Four: Effect of Defensive Pressure on International Women's Rugby Sevens	
Attacking Skills Frequency and Execution	77
Abstract	77
Introduction	77
Methods	80
Experimental Approach to the Problem.....	80
Subjects.....	80
Training Analysis.....	80
Reliability	87
Statistical Analysis	87
Results	88
Discussion.....	91
Conclusion	94
Chapter Five: Discussion	95
Movement Patterns of Training Camps.....	96
Technical Skills of Training Camps.....	98
Conclusion	100

Practical Applications	103
Limitations	104
Movement Patterns Study	104
Technical Skills Study	105
Directions for Future Research	106
References	109
Appendices	121
Appendix 1: Participant Information	121
Appendix 2: Participant Consent Form	124
Appendix 3: Coding Template	126

Conference Proceedings

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List of Figures

Figure 1: Structure of performance analysis and the sub-disciplines.	41
Figure 2: The relationship between defensive pressure and the frequency of conventional, cut-out, dummy, switch and offload passes.	88
Figure 3: The relationship between defensive pressure and the frequency of good, moderate and poor passes.	89
Figure 4: The relationship between defensive pressure and the frequency of successful and unsuccessful catches, evasive moves and line breaks.	90

List of Tables

Table 1: A summary of the GPS and heart rate thresholds used in men's rugby sevens studies.	11
Table 2: A summary of the GPS and heart rate thresholds used in women's rugby sevens studies.	14
Table 3: A summary of the movement patterns and heart rate of men's rugby sevens matches.	18
Table 4: A summary of the movement patterns and heart rate of women's rugby sevens matches.	23
Table 5: A summary of the injury data from rugby sevens matches.....	36
Table 6: A summary of the validity of 1 Hz, 5 Hz and 10 Hz GPS units.	44
Table 7: A summary of the inter-unit reliability of 1 Hz, 5 Hz and 10 Hz GPS units.	49
Table 8: A summary of the schedule and analysed data of women's rugby sevens preparation training camps and tournaments.	61
Table 9: Comparison of the absolute GPS data between an average session and individual sessions of women's rugby sevens training camps.	66
Table 10: Comparison of the relative GPS data between an average session and individual sessions of women's rugby sevens training camps.	69
Table 11: Description and distribution of time spent in each game-based drill for all training camps.	82
Table 12: Distribution of time spent and the number of passes performed in each type of defensive pressure.....	86

Abbreviations

CMJ	Countermovement jump
GPS	Global Positioning System
HIR	High-intensity running
HR	Heart rate
HR max	Maximum heart rate
IRB	International Rugby Board
LIR	Low-intensity running
MIR	Medium-intensity running
n	Number
RPE	Rating of perceived exertion
NSPR	Number of sprints
SPR	Sprinting
sRPE	Session rating of perceived exertion
VT _{2speed}	Running speed at the second ventilatory threshold
VO ₂ max	Maximal oxygen uptake
z	Z-score

Units of Measurement

%	Percentage
% HR max	Percentage of maximum heart rate
/hour	Per hour
/min	Per minute
AU	Arbitrary units
b/min	Beats per minute
cm	Centimetre
CV	Coefficient of variation
G	Gravitational force
Hz	Hertz
ICC	Intraclass correlation coefficient
IQR	Interquartile range
Kg	Kilogram
Km/h	Kilometres per hour
m	Metre
MD	Mean difference
min	Minute
m/min	Metres per minute
m/s	Metres per second
m/s/s	Metres per second per second
r	Pearson correlation
s	Second
SD	Standard deviation
SEE	Standard error of estimate
SEM	Standard error of measurement
SR	Standard residual
TEM	Typical error of measurement
χ^2	Chi squared

Chapter One: Introduction

Rugby Sevens

Rugby sevens, which is also known as seven-a-side rugby, is an exciting sport that involves intermittent bouts of high-intensity activity, with short recovery intervals. The combination of the frequent high-intensity activities and short recovery periods would suggest that rugby sevens places considerable physical demands on players (55). Since the inclusion of men's and women's rugby sevens as an Olympic sport in the 2016 Olympic Games in Rio de Janeiro, Brazil, rugby sevens has increased in popularity, becoming one of the fastest growing sports internationally (104).

Rugby sevens is a variation of traditional 15-a-side rugby union, played on a full-size rugby field with teams made up of seven players, three forwards and four backs. While forwards compete in set-piece plays such as scrums and line-outs and the backs do not, these positional groups are not as clearly defined as those in rugby union. The positional groups in rugby sevens are not as clearly defined due to the greater similarities in the movement patterns and technical skills of matches for rugby sevens forwards and backs (57, 98). Rugby sevens consists of two seven-minute halves with a two-minute half-time interval, with the exception of finals, where match play is extended to 10-minute halves (122). Rugby sevens also has other rule modifications to rugby union to create a more expansive and exciting style of play. Modified rules associated with rugby sevens include, a total of 12 players in a squad for the duration of a tournament, with five substitute players and five interchanges allowed during the match, compared to rugby union with eight substitute players and eight interchanges allowed (122). All conversion attempts in rugby sevens are performed by drop-kicking rather than place kicking the ball, and must be taken within 40 seconds of scoring a try. Kick-offs are taken by the team that has just scored, rather than the conceding team as occurs in rugby union (122).

Rugby sevens first originated from the Scottish town of Melrose in 1883 (121). The popularity and participation of rugby sevens has evolved since the first game in 1883, culminating in the inaugural men's Rugby Sevens World Cup that took place in Scotland in 1993 (7, 121). The Rugby Sevens World Cup has continued to develop and has twice, in 2009 and 2013 had both men's and women's competitions together (121), with the Australian women's rugby sevens team winning the first Women's Sevens World Cup in Dubai in 2009 (7). The introduction into the 1998 Commonwealth Games for men's rugby sevens ultimately resulted in the International Rugby Board (IRB) World Series in 1999 –

2000 (7), that is now known as World Rugby Sevens Series. The Sevens Series consist of 15 core teams that include Argentina, Australia, Canada, England, Fiji, France, Japan, Kenya, New Zealand, Portugal, Samoa, Scotland, South Africa, USA and Wales for the 2014 – 2015 tournaments, with the remaining place at each round filled by an invited team. The IRB Women's Sevens World Series was introduced in the 2012 – 2013 season consisting of an invitational tournament in Dubai, United Arab Emirates in November 2012. Women's Sevens World Series in Houston, USA in February, followed by Guangzhou, China in March 2013 and Amsterdam, Netherlands in May 2013. IRB Women's Sevens Challenge Cup was held in London, England in May 2013, with the last tournament for the season including the Rugby Sevens World Cup in Moscow, Russia in June 2013. The IRB Women's Sevens World Series is now known as World Rugby Women's Sevens Series, which continues to develop and now includes six rounds in the United Arab Emirates, Brazil, USA, Canada, England and the Netherlands. The competition structure for women's rugby sevens is similar to the men's series and in 2014 – 2015 each 12 team tournament consists of 11 core teams including Australia, Canada, China, England, Fiji, France, New Zealand, Russia, South Africa, Spain and the USA, with the remaining place filled by an invited team (123). Both the men's and women's rugby sevens competitions have continued to develop with the introduction into the 2016 Olympic Games in Rio de Janeiro, Brazil and the 2018 Commonwealth Games on the Gold Coast, Australia being the first Olympic and Commonwealth Games to include both men's and women's rugby sevens (123).

Due to the format of rugby sevens matches an entire tournament can be played over two to three consecutive days, with teams playing between four to six matches depending on results with approximately three hours between matches (116). A total of 45 games are played during international men's tournaments and 34 matches for international women's rugby sevens tournaments. The World Rugby Sevens Series consists of 16 teams, with four pools of four teams and Women's Sevens Series includes 12 teams with three pools of four teams (123, 124). Each team plays the other three teams in their pool on day one of the tournament to determine the pool standings. The top two teams from each pool progress to the quarter-finals, with the four winning teams from the quarter-finals progressing to the Cup semi-finals and final and the four losing teams play-off in the Plate competition. The two bottom ranked teams from each pool play-off in quarter-finals as well, with the four winning teams progressing to the Bowl semi-finals and final and the four losing teams play-off in the Shield competition (124). The Women's Sevens Series knockout stage is slightly different to the men's competition due to only 12 teams competing in the Women's Sevens Series. The top two teams from each pool along with the top two third placed teams progress to the quarter-finals, with the four winning teams progressing to the Cup semi-finals and final and

the four losing teams competing in the Plate competition. The remaining teams, which include the bottom ranked teams and the last ranked third placed team from each pool play in the Bowl knockout stage, with no Shield competition for women's rugby sevens tournaments (123). Points are allocated based on the finishing position at the end of the tournament for each of the rounds during the series with an overall champion crowned at the end of the series from the points accumulated throughout the World Rugby Sevens Series and Women's Seven Series (123, 124).

During the 2012 – 2013 international season, the Australian women's rugby sevens program was decentralised and comprised of semi-professional players. In order to transition from a semi-professional to a more professional player preparation structure and prepare for the 2016 Olympic Games almost all the core teams of the World Rugby Women's Sevens Series including Australia, Canada, China, England, Fiji, France, Russia, South Africa, Spain and the USA have programs that are now centralised, with the exception of New Zealand that maintains a decentralised program (21). While Australia and the other core teams in Women's Sevens Series have centralised programs, these centralised programs are newly developed and may only have 16 contracted players for a 12 member squad for each tournament, with injury or loss of form requiring additional players to be introduced for training camps and tournaments. In addition to newly centralised programs providing a more professional preparation structure, national championships are played throughout many core countries of the Women's Sevens Series including Australia, in order to develop and identify talent for international tournaments. The players that compete in the national championships for their state are semi-professional athletes living in a variety of locations, that utilise training camps to prepare for competition. While the core teams of Women's Sevens Series are centralised the qualifying teams who play-off for a spot in each round of the Women's Sevens Series still have decentralised programs making training camps an important part of team preparation (21).

Decentralised programs that employ preparation training camps to enable team training sessions, and centralised programs that utilise training camps for additional players outside of the contracted team, present unique logistical challenges for players, coaching staff and administrators. Logistical challenges include players organising work and study commitments around training camps, tournaments, domestic and international travel. The semi-professional status of teams not in the Women's Sevens Series core countries with centralised programs, affects individual and team preparation due to the fact that not all players are available for all training camps and tournaments. Subsequent challenges for

rugby sevens teams include the lack of a centralised program, or new players being introduced for tournaments to a centralised program. The distribution of players in a variety of locations makes it difficult to have regular team training, with the coaching staff relying on individuals to train by themselves or within smaller local groups, often with less talented and physically prepared athletes. The rapid evolution of women's rugby sevens means majority of players have no rugby background, with players being recruited from other sports such as touch football, Oztag, Australian football and netball. The recruitment of players with no rugby background, requires players to rapidly develop rugby sevens specific skills, tactical awareness and physical attributes to enable them to perform in rugby sevens.

Regular training camps are held by rugby sevens teams to facilitate team cohesion and minimise the effects of the players decentralisation challenges or newly introduced players to a centralised program. Training camps are typically three to four days in duration and consisted of multiple sessions per day, comprised predominately of on-field skill sessions and focused on technical and decision making skills in context with team tactics. Preparation training camps are scheduled two to three weeks prior to a tournament highlighting the need for the coaching and strength and conditioning staff to monitor these training camps. The physical, technical and tactical demands of training camps are monitored to maximise the benefits of training and to determine if the physical, technical and tactical demands are being sufficiently challenged to optimise performance during tournaments.

Optimising team performance for tournaments during training camps can be a difficult task, because of the limited days to prepare a team while also managing the complex interaction between the technical and tactical skill development and the physical demands. Quantifying the physical demands is now commonplace in high performance sport, with a variety of internal (rating of perceived exertion (RPE), heart rate (HR)) and external (Global Positioning System (GPS) outcomes that quantify and reflect the players' movement patterns) measures being used in a training context. The interaction between the physical, technical and tactical demands is demonstrated by an increase in the movement patterns and internal load as assessed by RPE often resulting in changes to skill frequency and or performance. Skill acquisition and or the adoption of new tactical approaches may be compromised with increased physical demands or defensive pressure, thereby negatively affecting the frequency and or performance of selected skills. During small sided games it was demonstrated that as the field size is reduced, players have increased frequency of skills, whereas increasing the field size increases the physical demands of movement patterns and RPE, with skills performed less frequently (13, 45, 68, 91). Small sided games research highlights the complex interaction that occurs between the physical, technical and tactical

demands, with the balance between physical, technical and tactical demands important for rugby sevens preparation training camps. Without monitoring the movement patterns in conjunction with the technical and tactical skills, it is difficult for the coaching staff to ensure their players are being exposed to optimal physical, technical and tactical demands during training.

Due to the limited days that coaches have to prepare the Australian women's rugby sevens team for competition, game-based drills are an important part of the training camp structure. Game-based drills address key elements of matches and are used to develop the physical, technical and tactical demands required for international success. One of the most important constraints the coaches manipulate during these game-based drills is the level of defensive pressure (70). It has been demonstrated that performance, assessed by skill accuracy, is reduced during basketball and soccer training with increased defensive pressure (70, 82). The use of full-court and quarter-court basketball games have demonstrated that shooting accuracy decreases with increased defensive pressure (70). Defensive pressure is an important consideration during game-based drills of rugby sevens training camps, gaining some insight into the effects of defensive pressure on skill frequency and execution is very important for rugby sevens preparation training camps. By understanding the effects of defensive pressure from previous research, this not only provides comparisons to the present research, but understanding why defensive pressure during training can alter skill frequency and execution. Despite the acute decrements in skill execution that may occur with increased defensive pressure during training, it is important that players learn to perform skills under defensive pressure similar to matches if they are to be successful in national and international tournaments. Defensive pressure needs to be progressed and utilised by the coaching staff if they are to optimise the development of technical skills and tactical awareness during training. The progression of defensive pressure is particularly essential during the learning process of new skills or tactics (16).

There are no peer-reviewed data available on the physical demands of rugby sevens preparation training camps, or the effects of different levels of defensive pressure on the frequency and execution of rugby sevens skills in either men's or women's rugby sevens players. Physical and technical demands of preparation training camps would appear vital to the selection of appropriate task constraints during training drills. The task constraints implemented during training drills need to allow for the learning of new technical and tactical skills and provide sufficient physical challenge for the developments in match performance to occur.

Project Aims

The aim of the present thesis was to undertake an observational study design to quantify the movement patterns, technical and tactical demands of women's rugby sevens training camps, in an attempt to assist coaches to better prepare players for the demands of competition.

To achieve the overall goal, two studies were proposed. The primary aims of the two studies in the present thesis were:

1. Quantify the movement patterns of preparation training camps for international women's rugby sevens players.
2. Determine the effects of the level of defensive pressure on the frequency and execution of key attacking skills for international women's rugby sevens players during training camps.

Chapter Two: Literature Review

Introduction

The literature review commences with a discussion of the GPS definitions and thresholds used within the rugby sevens literature followed by an overview of the rugby sevens research to establish what is known about rugby sevens and the gaps which exist in the literature. A description of performance analysis and the sub-disciplines of time-motion analysis and notational analysis are provided as these two areas of performance analysis are the main research paradigms used in the present thesis. The time-motion analysis section provides data on the validity and reliability of GPS units with the notational analysis section examining performance indicators and operational definitions to enhance validity and reliability. The research tools used including GPS and notational analysis are fundamental to the usefulness of performance analysis in improving sporting performance.

Search Strategies

A systematic review of the literature was conducted, investigating rugby sevens, the validity and reliability of GPS units and notational analysis conducted during team sports. The systematic review utilised the following methodology:

Databases searched: Science Direct; Sport Discus; Medline (OVID); Embase; Pubmed
The last literature review was conducted on the 3rd of July 2015.

Keywords: rugby sevens OR rugby union sevens OR sevens

Keywords: GPS OR Global Positioning System AND GPS receivers AND GPS 1 Hz AND GPS 5 Hz AND GPS 10 Hz AND time-motion analysis AND reliability AND validity

Keywords: notational analysis OR match analysis OR performance analysis AND sport OR rugby AND sport video analysis

Reference lists of identified journal articles were scanned to identify relevant literature. Criteria for inclusion in the review were dependent on the quality of information available and the accessibility to full-text journal articles.

Global Positioning System Definitions and Thresholds Used in the Rugby Sevens Literature

An understanding of the GPS definitions and thresholds used for specific variables is important to provide context for comparisons and discussions throughout the literature review and thesis. Similar to Cummins et al. (25) who provided an excellent overview of the velocity zones used in the wider GPS sports literature, it was essential to provide an overview of the GPS sampling frequencies, definitions and thresholds at the start of the present literature review to better enable comparisons between studies results throughout the thesis. Table 1 demonstrates the definitions used within data analysis to classify GPS and HR outcomes for men's rugby sevens players, while Table 2 provides the same detail for women's rugby sevens players.

The number of studies that investigated the movement patterns of rugby sevens matches through the use of GPS was 14, with nine (40, 49, 55, 57, 80, 97, 98, 103, 105) of the studies focusing on men's players and five studies (17, 18, 26, 88, 104) including women's rugby sevens players. Twelve studies (17, 18, 26, 40, 49, 55, 57, 80, 88, 97, 98, 104) were conducted on international players, and five studies (17, 55, 88, 97, 103) using national players, with four of these studies (17, 55, 88, 97) comparing international and national players and one study conducted on recreational players (105). Analysis of all rugby sevens studies revealed variations in the sampling frequencies of the GPS units, with a trend for increased sampling frequencies in more recent studies (18, 40). The trend for increasing sampling frequencies in more recent studies reflects the increased sampling frequencies of more recent GPS units and the tendency for greater validity and reliability than older, 1 Hz units (62, 111).

All 14 rugby sevens match studies used absolute velocity zones that were the same for all players, with four of these studies (17, 18, 40, 80) basing velocity zones on the results of physiological testing. Six of the 14 studies analysing rugby sevens matches used km/h to define velocity zone thresholds, however all units in Tables 1 and 2 have been converted to m/s for consistent units of measurement to enable direct comparisons between studies. The studies that originally presented data as km/h included the following velocity zones, standing / walking (0 – 1.7 m/s), jogging (1.7 – 3.3 m/s), cruising (3.3 – 3.9 m/s), striding (3.9 – 5 m/s), high-intensity running (HIR) (5 – 5.6 m/s) and sprinting (> 5.6 m/s) (26, 49, 88, 103-105). Granatelli et al. (49) used the same velocity zones, however divided the classifications into two broader zones including low-intensity running (LIR) (< 3.9 m/s) and HIR (> 3.9 m/s).

The additional eight studies from the rugby sevens literature described velocity zones in units of m/s. Higham et al. (55, 57) used the following velocity zones 0 – 2 m/s, 2 – 3.5 m/s, 3.5 – 5 m/s, 5 – 6 m/s and ≥ 6 m/s. Ross et al. (98) also used the same velocity zones, however used a broader classification which included LIR (< 5 m/s) and HIR (> 5 m/s). Clarke et al. (17) used similar thresholds including < 2 m/s, 2 – 3.5 m/s, 3.5 – 5 m/s and > 5 m/s, this was however, the first study to have velocity zones specific to women's rugby sevens players. The other common classification threshold used during rugby sevens studies was approximately 4.2 m/s to describe HIR (40, 80, 97). Regardless of the units of measurement to define velocity zones, the velocity zones were similar for all velocity classifications with 0.4 m/s or less between the two units of measurement, with the exception of Clarke et al. (17). Clarke et al. (17) used reduced velocity zones for women's rugby sevens players compared to what has been used previously in other studies of men's and women's rugby sevens players, with the greatest reduction evident regarding the difference of 1.5 m/s for the starting velocity of HIR. The velocity classifications that used km/h as the original unit of measurement had more velocity categories to describe running speeds compared to the m/s classifications. However, the actual velocity, regardless of being presented in km/h or m/s are comparable. The threshold for HIR was the same for both units of measurement with 5 m/s being the starting threshold. However, sprinting classifications defined in km/h and m/s varied by 0.4 m/s which could have an effect on the distances covered between the two sprinting zones. The effect of the small differences of 0.4 m/s between velocity zone definitions have the potential to be more pronounced for the HIR zones compared to the LIR zones.

The evolution of velocity zones is further evident in the rugby sevens research with some recent publications basing HIR on running speed at the second ventilatory threshold (VT_{2speed}) (17, 18, 80) and average velocity at maximal oxygen uptake (VO_2 max) (40). Using physiological testing, such as VT_{2speed} to determine individual velocity zones has been shown to correlate with a player's aerobic fitness, HIR capacity and to provide an accurate representation of the HIR performed (18). Physiological based velocity zones applied to each individual player may be more time consuming than traditional velocity zones and require time for the test to be conducted, but also consistent retesting to ensure physiological based velocity zones are up to date. In order to be able to readily compare women's rugby sevens players a predetermined velocity zone of 3.5 m/s was suggested for the starting velocity to quantify HIR based on VT_{2speed} of a women's rugby sevens team (18). The reduced HIR zone based on VT_{2speed} of women's rugby sevens players has been used to describe velocity zones for women's rugby sevens players that include < 2 m/s, 2 – 3.5 m/s,

3.5 – 5 m/s, > 5 m/s (17). Two additional studies (40, 80) also employed velocity zones for a whole team that were based on physiological testing (VO_2 max) of individual players. The velocity zones included > 4.21 m/s (40) and 4.17 – 10 m/s (80) to quantify HIR. Perhaps as a result of the greater individualisation of velocity zones based on physiological assessments, the classification of velocity zones particularly HIR have recently decreased in an effort to more accurately classify and quantify HIR. For example, research into velocity zones has identified that the use of men's velocity zones of 5 m/s for HIR underestimates women's movement patterns by approximately 30% compared with $\text{VT}_{2\text{speed}}$ of 3.5 m/s (18). From the five studies that investigated women's rugby sevens match demands, three studies (26, 88, 104) defined velocity zones that were consistent with velocity zones used for men's rugby sevens players. The use of men's velocity zones underestimates HIR distances due to the significantly greater aerobic power and sprinting velocity of men's compared to women's rugby seven players (18). However, such an approach enables direct comparisons between the two genders for their absolute values.

Despite the lack of consistency with velocity zones throughout the rugby sevens literature, HR classifications were all based on maximum heart rate (HR max) except for Del Coso et al. (26) who only reported beats per minute. Accelerations, decelerations and impacts have also been reported in a small number of studies, that could be potentially due to the limited research surrounding rugby sevens matches. Accelerations, decelerations and impacts are included in five studies involving men's players (40, 55, 57, 80, 103) and two studies involving women's players (17, 88). The studies quantifying accelerations, decelerations and impacts have limited consistency in the definitions for these variables, only two studies used the classification for accelerations and decelerations of 2 – 4 m/s/s, > 4 m/s/s and - 2 to - 4 m/s/s, < - 4 m/s/s (40, 55) respectively. Additional definitions used to describe accelerations and decelerations included ≥ 1 m/s/s and $\leq - 1$ m/s/s (57) respectively and accelerations ≥ 2.78 m/s/s (80), > 1.5 m/s/s, > 2 m/s/s, > 2.5 m/s/s and > 2.75 m/s/s (88). Impacts were only investigated in three studies using the following zones, ≥ 5 gravitational force (G) and 7 – 8 G, 8 – 10 G and > 10 G (17, 57, 103). The varying classifications with velocity, acceleration, deceleration and impact zones make comparisons between different studies difficult. However, by understanding the classification threshold for each variable, context around what is actually being measured is provided and enables easier comparisons of particular studies within the rugby sevens literature.

Table 1: A summary of the GPS and heart rate thresholds used in men's rugby sevens studies.

Study	Participants	GPS sampling frequency	Velocity zones	Accelerations	Decelerations	Impacts	Heart rate
Furlan et al. (40)	International men	15 Hz	HIR > 4.21 m/s	Moderate (2 – 3 m/s/s) High (3.1 – 4 m/s/s) Very high (> 4 m/s/s)	Moderate (- 2 to - 3 m/s/s) High (- 3.1 to - 4 m/s/s) Very high (< - 4 m/s/s)		
Granatelli et al. (49)	International men	1 Hz	LIR (< 3.9 m/s) HIR (> 3.9 m/s)				% HR max
Higham et al. (55)	International men	5 Hz	0 – 2 m/s, 2 – 3.5 m/s, 3.5 – 5 m/s, 5 – 6 m/s and ≥ 6 m/s	Moderate (2 – 4 m/s/s) High (> 4 m/s/s) (minimum duration of 0.4 s)	Moderate (- 4 to - 2 m/s/s) High (< - 4 m/s/s) (minimum duration of 0.4 s)		
Higham et al. (57)	International men	15 Hz	0 – 2 m/s, 2 – 3.5 m/s, 3.5 – 5 m/s, 5 – 6 m/s and ≥ 6 m/s	≥ 1 m/s/s (minimum duration of 1 s)	≤ - 1 m/s/s (minimum duration of 1 s)	≥ 5 G	% HR max

Murray et al. (80)	International men	10 Hz	HIR (4.17 – 10.0 m/s)	≥ 2.78 m/s/s (minimum duration of 0.4 s)		
Ross et al. (98)	International men	4 Hz	LIR (< 5 m/s) HIR (≥ 5 m/s)			
Ross et al. (97)	International/ national men	4 Hz	LIR (< 4.16 m/s) HIR (≥ 4.16 m/s) VHIR (> 6 m/s)			
Suarez-Arrones et al. (103)	National men	15 Hz	Walking (0 – 1.7 m/s) Jogging (1.7 – 3.3 m/s) LIR (3.3 – 3.9 m/s) MIR (3.9 – 5 m/s) HIR (5 – 5.6 m/s) Sprinting (> 5.6 m/s)	7 – 8 G 8 – 10 G > 10 G	< 60% HR max 61 – 70% HR max 71 – 80% HR max 81 – 90% HR max 91 – 95% HR max > 95% HR max	
Suarez-Arrones et al. (105)	Recreational men	1 Hz	Standing / walking (0 – 1.7 m/s) Jogging (1.7 – 3.3 m/s) Cruising (3.3 – 3.9 m/s) Striding (3.9 – 5 m/s) HIR (5 – 5.6 m/s) Sprinting (> 5.6 m/s)		< 60% HR max 61 – 70% HR max 71 – 80% HR max 81 – 90% HR max 91 – 95% HR max > 96% HR max	

Blank spaces within the table indicate that the authors did not report on the specific variable.

G = Gravitational force, HIR = High-intensity running, HR max = Maximum heart rate, Hz = Hertz, LIR = Low-intensity running, km/h = Kilometres per hour, m/s = Metres per second, m/s/s = Metres per second per second, MIR = Medium-intensity running, s = Second, VHIR = Very high-intensity running.

Table 2: A summary of the GPS and heart rate thresholds used in women's rugby sevens studies.

Study	Participants	GPS sampling frequency	Velocity zones	Accelerations	Impacts	Heart rate
Clarke et al. (18)	International women	15 Hz	Running (> 3.5 m/s) HIR (> 5 m/s) VT _{2speed}			
Clarke et al. (17)	International/national women	5 Hz	< 2 m/s, 2 – 3.5 m/s, 3.5 – 5 m/s and > 5 m/s		8 – 10 G > 10 G	
Del Coso et al. (26)	International women	5 Hz	Standing / walking (0 – 1.7 m/s) Jogging (1.7 – 3.3 m/s) Cruising (3.3 – 3.9 m/s) Striding (3.9 – 5 m/s) HIR (5 – 5.6 m/s) Sprinting (> 5.6 m/s)			b/min
Portillo et al. (88)	International/national women	15 Hz	Standing / walking (0 – 1.7 m/s) Jogging (1.7 – 3.3 m/s) Cruising (3.3 – 3.9 m/s) Striding (3.9 – 5 m/s) HIR (5 – 5.6 m/s) Sprinting (> 5.6 m/s)	> 1.5 m/s/s > 2 m/s/s > 2.5 m/s/s > 2.75 m/s/s		< 60% HR max 61 – 70% HR max 71 – 80% HR max 81 – 90% HR max 91 – 95% HR max > 95% HR max

Suarez- Arrones et al. (104)	International women	1 Hz	Standing / walking (0 – 1.7 m/s) Jogging (1.7 – 3.3 m/s) Cruising (3.3 – 3.9 m/s) Striding (3.9 – 5 m/s) HIR (5 – 5.6 m/s) Sprinting (> 5.6 m/s)	< 60% HR max 61 – 70% HR max 71 – 80% HR max 81 – 90% HR max 91 – 95% HR max > 96% HR max
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Blank spaces within the table indicate that the authors did not report on the specific variable.

b/min = Beats per minute, HIR = High-intensity running, HR max = Maximum heart rate, Hz = Hertz, km/h = Kilometres per hour, m/s = Metres per second, m/s/s = Metres per second per second, VT_{2speed} = Running speed at the second ventilator threshold.

Rugby Sevens

Physical Demands of Rugby Sevens Matches

The physical demands of rugby sevens matches have been quantified using GPS units and HR monitoring and are presented in Table 3 for men and Table 4 for women. All 14 rugby sevens studies analysed matches through GPS, seven studies (17, 26, 49, 57, 88, 103-105) also used HR monitoring to provide further insight into the physiological cost of rugby sevens matches. As previously stated accelerations, decelerations and impacts have only been investigated to a limited degree with six (40, 55, 57, 80, 88, 103), three (40, 55, 57) and three (17, 57, 103) studies respectively, involving analysis of these variables.

Research into men's and women's rugby sevens has demonstrated that a total distance of approximately 1500 m (98, 103-105) is covered during a full rugby sevens match, with distances ranging from 1066 m (18) to 1642 m (88). The high-intensity of rugby sevens is demonstrated by the relative distance of approximately 100 m/min (17, 18, 40, 57, 80, 88, 97, 103) performed with relative distances covered between 86 m/min (80) to 120 m/min (55) during both men's and women's rugby sevens matches. Rugby sevens running intensities have been shown to be substantially greater than the m/min typically found in similar level 15-a-side rugby union (95). The high relative running intensities covered during rugby sevens is influenced by the HIR and sprinting movement patterns performed during matches. High-intensity running and sprinting have been identified as important indicators of match performance in rugby sevens and other team sports (65, 88, 107). During international women's rugby sevens matches players covered 4.4 m/min HIR and 6.1 m/min sprinting (26). Men's international players covered greater distances of 11.2 m/min HIR and 12.7 m/min sprinting (55), however both HIR and sprinting distances have been demonstrated to be variable, with standard deviations reported by Higham et al. (55) of 4.2 and 6.2 m/min for HIR and sprinting distances respectively. Based on the high relative variance of distance covered at HIR and sprinting, it is somewhat difficult to determine any differences between the distances covered by men and women in different velocity zones, with additional research required to investigate potential differences between men's and women's rugby sevens matches.

An essential part of speed characteristics required to be able to reach the high movement velocities during rugby sevens is the ability to repeatedly accelerate and decelerate when engaged in crucial offensive and defensive actions (26, 98, 99). During international women's rugby sevens matches, players performed 25 accelerations (> 1.5 m/s/s) (88) during a match. International men's players also performed 1.1 moderate ($2 - 4$ m/s/s)

accelerations per minute and 0.5 high (> 4 m/s/s) accelerations per minute of match play (55). While no studies have reported match data on decelerations for women's rugby sevens players, international men's rugby sevens matches have been quantified, with decelerations (< -1 m/s/s) occurring 3 times per minute (57). In addition to decelerations occurring 3 times per minute, international men's players also performed 1.5 moderate (-4 to -2 m/s/s) decelerations per minute and 0.3 high (< -4 m/s/s) decelerations per minute during rugby sevens matches (55).

In conjunction with and partly because of the high movement velocities and frequency of accelerations and decelerations performed during rugby sevens matches, players also experience a significant amount of impacts. Impacts are commonly reported in G, with a heavy impact or collision with an opposition player or players defined as an impact > 7 G (76, 103). The classification of impacts > 7 G is important as demonstrated by McLellan et al. (76), who found that the number of impacts > 7 G was associated with significant muscle damage up to 24 hours post match and as long as 48 to 72 hours for the higher impact zones ($8 - 10$ G, > 10 G) during elite rugby league competitions. National men's rugby sevens players perform 44 impacts > 7 G or 3 impacts per minute during a match (103). Further analysis demonstrated that the very heavy and severe impacts (> 8 G) occurred 17.8 times during national men's rugby sevens matches. Clarke et al. (17) also found similar results for the number of impacts > 8 G, with international women's rugby sevens players involved in 15.3 impacts per match. Physical impacts such as rucks, scrums and tackles have a high physiological cost (6) and are key skills for successful participation in rugby sevens (103). The highly intense nature of rugby sevens is further demonstrated through rugby sevens match studies investigating HR. Several studies have found rugby sevens players experience high HR, expressed as a percentage of HR max (49, 103, 105), with national men's and women's rugby sevens players shown to spend 32% and 37% respectively, of match time above 90% HR max (88, 103).

Table 3: A summary of the movement patterns and heart rate of men's rugby sevens matches.

Study	Participants/ sample size	GPS sampling frequency	Total distance	Relative distance	Distance covered in velocity zones	Accelerations	Impacts	Heart rate
Furlan et al. (40)	12 International men 6 matches	15 Hz		1 st half 98 m/min 2 nd half 90 m/min	HIR 1 st half 27 m/min 2 nd half 27 m/min	1 st half, 2 nd half Moderate 3.6, 3.3 /min High 0.4, 0.3 /min Very high 0.8, 0.7 /min		
Granatelli et al. (49)	9 International men 15 matches	1 Hz	1221 m 1 st half 643 m 2 nd half 578 m	1 st half 91 m/min 2 nd half 79 m/min	HIR 1 st half 25% 2 nd half 22%			Mean HR max 88% Time ≥ 90% HR max 86%

Higham et al. (55)	19 International men 11 International 16 National matches	5 Hz	International 120 m/min National 121 m/min 1 st half 120 m/min 2 nd half 113 m/min Sub 140 m/min	Running 23.5 m/min HIR 11.2 m/min SPR 12.7 m/min Sub 123% increase in distance covered SPR	Moderate 1.1 /min High 0.5 /min		
Higham et al. (57)	42 International men 22 matches	15 Hz	Forwards 96 m/min Backs 103 m/min	HIR Forwards 8.9 m/min Backs 10.2 m/min SPR Forwards 6.4 m/min Backs 9.8 m/min	Forwards 3.6 /min Backs 4.1 /min	> 5 G Forwards 26.2 /min Backs 23.5 /min	Mean HR max Forwards 87% Backs 85%

Murray et al. (80)	17 International men 24 matches	10 Hz		1 st half 103 m/min 2 nd half 86 m/min Full Match 86 m/min Early Sub 92 m/min Late Sub 100 m/min	HIR 1 st half 28.3 m/min 2 nd half 19.2 m/min Full Match 19.2 m/min Early Sub 21.1 m/min Late Sub 25.0 m/min	1 st half 1.3 /min 2 nd half 1.1 m/min Full Match 1.1 m/min Early Sub 1.2 /min Late Sub 1.5 /min
Ross et al. (98)	27 International men 50 matches	4 Hz	Forwards 1452 m Backs 1420 m		LIR Forwards 1202 m Backs 1173 m HIR Forwards 252 m Backs 249 m	

Ross et al. (97)	11 International 12 National men 92 International 37 National match files	4 Hz		International 105 m/min National 105 m/min	HIR International 26.9 m/min National 27.9 m/min SPR International 9.8 m/min National 8.4 m/min		
Suarez- Arrones et al. (103)	10 National men 23 matches	15 Hz	1611 m	102 m/min 1 st half 105 m/min 2 nd half 100 m/min Forwards 98 m/min Backs 107 m/min	HIR 4.7 m/min SPR 9.7 m/min NSPR 7.6	> 7 G 44.0	Mean HR max 86% Time > 90% HR max Forwards 37% Backs 28%

Suarez-Arrones et al. (105)	7 Recreational men 5 matches	1 Hz	1580 m No difference between halves	107 m/min	HIR 80 m SPR 138 m NSPR 1 st half 3.8 2 nd half 3.5	Mean HR max 1 st half 87% 2 nd half 89%
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Data are presented as mean values, blank spaces within the table indicate that the authors did not report on the specific variable.

/min = Per minute, G = Gravitational force, HIR = High-intensity running, HR = Heart rate, HR max = Maximum heart rate, Hz = Hertz, LIR = Low-intensity running, m = Metre, m/min = Metres per minute, NSPR = Number of sprints, SPR = Sprinting, Sub = Substitute player.

Table 4: A summary of the movement patterns and heart rate of women's rugby sevens matches.

Study	Participants/ sample size	GPS sampling frequency	Total distance	Relative distance	Distance covered in velocity zones	Accelerations	Impacts	Heart rate
Clarke et al. (18)	12 International women 5 matches	15 Hz	1066 m	105 m/min	Running 37% HIR 14%			
Clarke et al. (17)	12 International 10 National women 6 International 6 National matches	5 Hz	International 1180 m National 800 m	International 96 m/min National 94 m/min	HIR International 247 m National 173 m SPR International 161 m National 97 m		> 8 G International 15.3 National 11.8	
Del Coso et al. (26)	16 International women 6 matches	5 Hz		No caffeine 88 m/min Caffeine 95 m/min	No caffeine HIR 3.7 m/min SPR 4.6 m/min Caffeine HIR 4.4 m/min SPR 6.1 m/min			Mean HR No caffeine 164 b/min Caffeine 168 b/min

Portillo et al. (88)	10 International 10 National women 4 International 4 National matches	15 Hz	International 1642 m 1 st half 883 m 2 nd half 725 m	International 100 m/min National 87 m/min	International HIR 103 m SPR 119 m NSPR International 6.1 National 1.9	International 1 st half 13.3 2 nd half 11.5	Mean HR International 186 b/min Time spent 91 – 95% HR max International 1 st half 33.8% 2 nd half 31.6%
Suarez-Arrones et al. (104)	12 International women 5 matches	1 Hz	1556 m No difference between halves	102 m/min	HIR 57 m SPR 84 m NSPR 1 st half 2.5 2 nd half 2.8		Mean HR 1 st half 167 b/min 2 nd half 169 b/min

Data are presented as mean values, blank spaces within the table indicate that the authors did not report on the specific variable.

b/min = Beats per minute, HIR = High-intensity running, HR = Heart rate, HR max = Maximum heart rate, Hz = Hertz, m = Metre, m/min = Metres per minute, NSPR = Number of sprints, SPR = Sprinting.

Attributes of Rugby Sevens Players

Given the higher relative movement patterns of rugby sevens than traditional rugby union players, it is not unexpected that international men's rugby sevens players have less muscle mass and are leaner than international rugby union players (56). Rugby sevens players need to be lean as excess fat reduces a players power to weight ratio and allows for the potential of greater work output, due to proportionally lower energy demands of carrying the reduced body mass (78).

A moderate relationship was observed between 10 m sprint times and the number of line breaks and defenders beaten per match, while 40 m sprint times had a large relationship with the number of line breaks and defenders beaten per match (99). The moderate and large relationships with 10 m and 40 m sprint times respectively, suggest that maximal speed and acceleration are important in rugby sevens attack (99). Sprint performance at 5, 10 and 40 m has also been demonstrated to have a moderate relationship with tackle score. Furthermore effective defensive rucks, tackle score, dominant and turnover tackles have been demonstrated to moderately correlate with momentum at 10 m (99). Momentum at 10 m appears to be important for contact situations especially during defensive actions (99). The importance of sprint performance during rugby sevens has been highlighted in both attack and defence (99), with the ability to maintain sprinting performance over a match also an important attribute of rugby sevens players. Greater repeated sprint ability (assessed by 10 x 40 m sprints every 30 seconds) has been shown to moderately correlate with a greater work rate during a match, fewer handling errors and missed tackles (99). The ability to repeatedly sprint allows players to be involved in more game activities and execute skills under fatigue with less errors.

Lower body power (assessed by horizontal jump distance, body weight and weighted countermovement jumps (CMJ)) appear to be important determinants of match performance during rugby sevens (99). Longer horizontal jump distance has been shown to be moderately correlated with the number of defenders beaten and dominant tackles made and largely correlated to tackle score (99). Higher vertical jumps were shown to relate to improved performance during contact situations specifically during attacking and defensive rucks (99). Similar to other attributes of rugby sevens players, lower body performance seems to be important and be the most applicable to match performance. However, it is acknowledged that the only upper body assessments that were tested included, bench press and chin up one repetition maximum, with chin up results relating to contact situations including tackle score and effective defensive rucks (99). Rugby sevens players need to

possess a variety of attributes with sprint performance and lower body power important for both attacking and defensive aspects of match performance. The ability to repeatedly sprint assists with the performance of greater work rate and execution of skills under fatigue.

Differences in Tournament Level of Rugby Sevens Players

International women's rugby sevens players have been demonstrated to cover 17% more total distance compared to national players during matches (88). While international players covered greater distance than national players, the distribution of velocity zones is perhaps of greater importance, due to HIR and sprinting relating to scoring and defending, two outcomes that ultimately influence the match outcome (26, 102). International women's rugby sevens players covered 2.3 times greater distance in HIR than national players (88). Comparisons between tournament levels were also conducted by Higham et al. (55) during international and national men's rugby sevens matches. Specifically, Higham et al. (55) reported that the relative distance covered had no clear difference between international and national men's rugby sevens matches, while distances covered at HIR and sprinting only demonstrated small effect size differences, that may be a result of the large variations exhibited for rugby sevens matches. Despite only small effect sizes differences, international players covered 16% and 27% greater distances for HIR and sprinting respectively than national level players (55). Ross et al. (97) also found similar relative distances covered between national and international men's players, as well as small effect size differences in HIR and sprinting distance covered by international players. The small increases in high velocity distance covered between the two tournament levels may be explained by the greater speed characteristics of international players as demonstrated by Ross et al. (96) enabling international players to reach higher velocities within a match.

Women's rugby sevens players also perform a greater number of accelerations during international matches compared to national level matches. International women's rugby sevens players performed a significantly greater number of accelerations at 2, 2.5 and 2.75 m/s/s for the first and second half (88). In comparison to the results of women's rugby sevens players, international men's rugby sevens players exhibited trivial and small effect size differences in the number of moderate and high accelerations performed per minute during national and international tournaments (55). The study by Higham et al. (55) investigating men's rugby sevens players, included the same group of players, who competed at the different tournament levels and as result may account for no differences observed between the two tournament levels. Differences may occur between the movement patterns of national and international tournaments as a result of the differing physical, technical and tactical attributes of players that compete at different tournament levels.

The importance of speed and acceleration characteristics during rugby sevens were confirmed during sprint testing, where men's international players were 2.8%, 3.1% and 4.4% faster over 5, 10 and 40 m respectively, compared to national players (96). The speed characteristics of rugby sevens players during matches and sprint testing, highlight that speed is important for rugby sevens, however speed over longer distances may be of greater importance due to the large amount of space available for rugby sevens players (96). In addition to the importance of speed during rugby sevens, international men's players are shown to have greater lower body power compared to national level players, with a 5.8% greater horizontal jump distance and 23% greater relative power assessed by a CMJ (96). International women's rugby sevens players also exhibited greater lower body power (assessed by CMJ) compared to national players. International players had 15% greater peak power, 18% greater mean power and 6% greater peak velocity compared to national players (17). While the physical characteristics differ between international and national players, additional research is needed during rugby sevens matches to determine if differences in tournament levels consistently exist irrespective of the team assessed.

Due to the limited research around rugby sevens match demands, no men's rugby sevens studies have compared HR or impacts between tournament levels. Portillo et al. (88) however, compared HR between international and national women's rugby sevens players. International women's rugby sevens players had similar HR outcomes to national players for all HR zones, except time spent > 95% HR max where international players experienced significantly higher HR during the first and second half (88). The HR results suggest that international players are able to maintain a higher intensity during a match in comparison to national players, perhaps as a result of better developed physical capacities. International women's rugby sevens players also perform approximately 30% greater number of total and > 10 G impacts compared to national players (17). Muscle damage though (assessed by creatine kinase concentrations in the blood) demonstrated that international women's players had a large two-fold increase and national players had a very large four-fold increase at the end of the tournament compared to baseline (17). The higher number of impacts performed and lower creatine kinase concentrations of international compared to national rugby sevens players suggests that international players are able to perform greater workloads that are maintained over a tournament with less physiological disturbances due to greater aerobic capacities and the ability to withstand fatigue (17).

Comparisons between rugby sevens players of different tournament levels, suggest that women's rugby sevens players of international standard may cover greater distances during

games, particularly at HIR and sprinting, perform a higher number of accelerations and have greater time spent > 95% HR max than national level players. In comparison to differences in tournament level for women's players, men's rugby sevens players exhibited no significant differences between national and international tournament levels. International players were, however found to have greater sprint speed over 5, 10 and 40 m and lower body power than national level players (96). Additional research is required in both men's and women's rugby sevens matches to determine if differences in tournament level consistently exist regardless of the team analysed.

Differences in Positional Groups of Rugby Sevens Players

Positional groups in rugby sevens consist of three forwards and four backs, compared to the eight forwards and seven backs in traditional rugby union. While rugby sevens forwards compete in set-piece plays such as scrums and line-outs and the backs do not, these positional groups are not as clearly defined as those in rugby union due to the greater similarities in the physical and technical demands of matches for rugby sevens forwards and backs (57, 98).

National men's rugby sevens backs have been shown to cover slightly more relative distance (107 m/min) compared to forwards (98 m/min) during national matches (103). Higham et al. (57), however observed trivial to small differences for majority of the movement patterns between international men's forwards and backs. International men's forwards covered 8.9 m/min HIR and 6.4 m/min sprinting compared to backs that covered 10.2 m/min and 9.8 m/min HIR and sprinting respectively, with the effect size differences between the positional groups being only small. Small effect size differences between positional groups were also observed for accelerations, with international forwards performing 3.6 and international backs performing 4.1 accelerations per minute (57). Ross et al. (98) also found that the majority of movement patterns and technical skills had trivial to small effect size differences between positional groups, suggesting that match demands are relatively similar between international men's rugby sevens forwards and backs (98).

Similar to the movement patterns of rugby sevens forwards and backs there was no practical differences observed between forwards and backs for the number of impacts > 5 G or > 7 G (57, 103). The number of tackles performed by national forwards (7.4) and backs (4.1) however, had a large effect size difference (103). The discrepancy between the number of impacts and tackles performed may be explained by the potential relative lack of validity for measuring impacts with accelerometers contained inside GPS units. The lack of validity of the GPS accelerometers reflects the discrepancy in the number of moderate to serve

impacts recorded by the accelerometers within GPS units and the actual number of tackles and hit-ups coded from video footage (76). The limitation of GPS to quantify impacts may explain why no differences were observed between forwards and backs for the number of impacts even though there were differences for the number of tackles. It has also been demonstrated that there was no substantial differences between forwards and backs for mean heart rate during national (103) and international (57) men's rugby sevens matches. The percentage of time spent > 90% of HR max was however, substantially higher for forwards compared to backs (103). The difference in time spent > 90% HR max for forwards than backs has been attributed to the higher number of tackles performed by forwards, inducing greater internal loads than running (103). The current literature on rugby sevens suggests that physical demands, including movement patterns and HR responses are relatively similar between rugby sevens forwards and backs. The similarities between rugby sevens forwards and backs may mean that the requirement for positional specific training is less in rugby sevens than 15-a-side rugby.

Positional groups in rugby sevens also includes substitute players, who play an important role in rugby sevens due to the high levels of fatigue experienced during matches and tournaments. International and national men's substitute players (played less than four minutes of the 14 minutes per pool game) cover 24% more distance per minute during the second half compared to players who played a full match (55). The greater distance covered by substitutes in the second half is primarily a result of 123% and 110% greater HIR and sprinting distances respectively (55). Murray et al. (80) further investigated international men's substitute players by categorising the substitute players into late and early. Early substitute players came on in the first four minutes of the second half compared to late substitutes who came on in the last four minutes of the second half. Late substitute players were found to cover 16% more total distance, have 31% more HIR distances and 34% greater number of accelerations compared to players who played a full game (80). In addition, late substitute players covered greater relative distance (100 m/min) compared to early substitutes (92 m/min), although this was only a possible effect size difference, perhaps due to the relatively large variability of the results (80). The present findings highlight the importance of substitute players through their potential to influence the match outcome and also how the timing of substitute players is an important tactical decision used by coaching staff.

Fatigue during Rugby Sevens Matches and Tournaments

The highly intense, anaerobic nature of rugby sevens produces high levels of lactic acid and other metabolic by-products that are associated with muscle fatigue (108). Fatigue can however, be quantified in numerous ways. Within the rugby sevens literature, fatigue has been quantified by changes in the movement patterns, as assessed by GPS outcomes, and by differences in neuromuscular function assessed by CMJ performance, before and after match play. A common way to gain some insight into the possible effects of fatigue is via comparisons of sport movement patterns between the first and second half. It has been demonstrated that total distance covered per minute is reduced by 5% (55), 9% (40) and 11% (49) between the first and second half of international and national men's rugby sevens matches. Furthermore, a decline of 14% and 16% in the number of moderate and high accelerations per minute was observed between the first and second half during international and national men's rugby sevens matches (55). In contrast to differences observed between the two halves for distance covered by men's rugby sevens players, no significant differences were evident in the distance covered between the two halves for women's rugby sevens players (104). The variation in results between men's and women's rugby sevens matches may have been due to the sampling frequency of GPS units and the sample size of the studies. Studies that observed differences between the two halves investigated 11 (55), 15 (49) and 24 (80) international matches, compared to five international matches during the study by Suarez-Arrones et al. (104). In support of the findings from men's rugby sevens studies (49, 55), international women's rugby sevens players have exhibited substantial fatigue, with the mean running velocity decreasing during the match with the last quarter being the slowest (88).

In addition to the reductions in movement patterns between the first and second half, rugby sevens players also experience fatigue from the matches played over two consecutive days during a rugby sevens tournament (116). After a men's rugby sevens tournament of five matches, neuromuscular function (assessed through CMJ height) was shown to be reduced by 26% and remained reduced by 8% five days later (116). Clarke et al. (17) however, observed no substantial changes in CMJ performance over a two day international women's rugby sevens tournament. The fact that different variables were assessed during the CMJ may explain some differences. In addition to different CMJ variables assessed, differences between the CMJ results may be explained by the protocol differences, where Clarke et al. (17) assessed fatigue after the completion of each day as opposed to the morning after each day of the tournament (116), which may account for no observed changes in neuromuscular function. The fact that muscle damage (assessed by blood creatine kinase) peaks 24 hours

post match (76) may suggest that CMJ performance is not yet significantly reduced with assessment straight after each day of a tournament.

Despite no changes in CMJ measures, international women's rugby sevens players still experienced changes in GPS measures from day one to day two. A large effect size decrease of 8% was observed for relative distance and a moderate effect size decrease of 18% was evident for distance covered > 5 m/s, from day one to day two for international women's players. Impacts and low velocity movement patterns, however remained consistent across the tournament (17). Higham et al. (55) determined there was unclear to small differences in the movement patterns of the first match compared to the last match of a tournament. Ross et al. (98), who compared pool and cup matches of rugby sevens tournaments, concluded that movement patterns were similar across a tournament but there was high variability from match to match. A number of factors would be likely to influence the findings between the first and last match or pool and cup matches, the fixture of each tournament, with the potential for the first match or pool matches of a tournament to be easier than the last match or cup matches. The assessment of fatigue through GPS movement patterns as investigated by Higham et al. (55), Ross et al. (98) and Clarke et al. (17) have been demonstrated to be influenced by a number of factors including opponents, scoreline and the use of substitute players (80). From the literature review it is evident that rugby sevens players experience fatigue and muscle damage during tournaments, with research suggesting that the influence of fatigue on players' ability to maintain movement patterns across a tournament is relatively minor for men (55, 98) and potentially more significant in women (17). In men's rugby sevens matches the movement patterns are general maintained and therefore any fatigue that players experience either has a minimal effect or players' pace their movement patterns in anticipation for fatigue later on during the tournament.

The reductions in movement patterns, resulting from numerous factors including a fatigue effect, individual players' pacing, different opponents or team tactics, have been demonstrated between halves. However, fatigue between multiple days of rugby sevens tournaments is also an important factor underlying tournament performance. The influence of neuromuscular fatigue (assessed through CMJ height) and muscle damage (assessed through blood creatine kinase) on players is evident at the conclusion of men's rugby sevens tournaments (116), even though this may have a limited effect on the ability of players' to maintain movement patterns across matches within a tournament (55, 98). In contrast to the results of men's rugby sevens matches and tournaments, the opposite was true for women's

rugby sevens players who appeared to experience less fatigue between the days of a tournament as evidenced by no substantial changes in CMJ, but a reduced ability to maintain movement patterns from match to match (17). It is therefore concluded that further research is required to understand the effects that rugby sevens matches and tournaments have on neuromuscular fatigue for men's and women's players.

Technical Demands of Rugby Sevens Matches

Attacking Performance Indicators

Technically rugby sevens differs from traditional 15-a-side rugby union in several ways. The majority of rugby sevens game time is undertaken in open play, requiring backs as well as forwards to be highly proficient in passing and catching, with these skills and movements performed at high velocities and under high levels of defensive pressure (53, 54, 61). During international men's rugby sevens tournaments, higher ranked teams had greater attacking efficiency (assessed by fewer passes per try) and an increased ability to maintain possession of the ball (54). Efficiency in attack and maintaining possession have been highlighted as key determinants of success during rugby sevens matches (54). In the 2001 IRB World Sevens Series, successful teams (defined as winning $\geq 70\%$ of matches) averaged 51% of time in possession and seven passes per try compared to unsuccessful teams (winning profile of $< 70\%$) averaged 43% of the time in possession and 11 passes per try (61).

International men's players also displayed greater attacking skills compared to national players. An International player performs 0.34 passes per minute compared to 0.25 for national players. National players however, performed a greater number of ineffective passes and had more handling errors (97). By retaining possession during passing, catching, rucks and mauls, winning teams obtain greater attacking opportunities and score a higher number of points (53). More errors per match were associated with worse rankings during international tournaments (54). By limiting errors and retaining possession of the ball, successful teams are able to limit the time their opposition are in possession and their opportunities for scoring points. Better tournament rankings were also associated with more tries per entry into the opposition's 22 m zone and passes per match (54). In addition to more passes per match being associated with better tournament rankings, more passes per try were associated with worse rankings during international tournaments (54) and an increased possession time per try was associated with worse team rankings during men's sevens series (52). Efficiency in attack also differentiates quarter-finalists and semi-finalists, with the semi-finalists having more possession and converting it more efficiently into points (109). Collectively, these results suggest that while maintaining possession is important, a

focus on merely maintaining possession may not be an optimal strategy, with efficiency in attack just as important.

Consistent with the tactics that just maintaining possession is not the most effective attacking strategy, successful rugby sevens teams have been shown to execute an evasive style of play, playing with greater width and keeping the ball in open play as opposed to going into contact (61). Consistent with the evasive style and keeping the ball in open play tactics of successful teams, Higham et al. (53) demonstrated that teams in possession of the ball with a higher number of rucks and mauls per minute of possession scored less points and therefore reduced the likelihood of winning. Successful teams also had fewer conventional and loop passes and more cut-out and dummy passes (61). Efficiency in attack may be achieved with an evasive, open style of play through non-conventional passes such as cut-outs and offloads, that put more pressure on the defence by requiring greater decision making due to increased task complexity (defined as the number of parts or components in the amount of information processing demands that characterise skill) (75). The effective tactical approach of rugby sevens suggest that successful teams are better able to utilise these non-conventional passes while still retaining possession and keeping the ball in open play.

Defensive Performance Indicators

While time in possession during rugby sevens matches is important, defence and actions performed without possession have also been shown to discriminate between rugby sevens team rankings and tournament level (54, 97). Successful and better tournament ranked rugby sevens teams perform more successful tackles and miss fewer tackles (54, 61) while better team ranking during men's sevens series was associated with conceding fewer tries per match (52). International players also performed more effective tackles and fewer ineffective and missed tackles compared to national players (97). Gaining turnovers from the opposition has been demonstrated to increase scoring opportunities due to the vulnerability of the opposition in transition from attack to defence (52). Gaining 4.4% more possession from opposition rucks was demonstrated to have a 60% improvement in team ranking during men's Sevens World Series (52). In addition to gaining possession from opposition rucks improving team ranking, defensive ruck effectiveness (defined as defensive rucks attended in which a player makes an effective counter ruck) was shown to distinguish between international (83%) and national players (53%) (97). Successful teams and international players display superior defensive skills which have been suggested to relate to the ability to resist fatigue and make better decisions during a match (97).

Epidemiology of Injury in Rugby Sevens

A link between fatigue and injuries during rugby sevens tournaments has been established due to the higher incidences of injuries in the second half compared to the first, and in the knockout (day two) compared to pool (day one) stages of rugby sevens tournaments (37, 55, 78). The risk and severity of injuries in rugby sevens was higher than that observed during rugby union matches (37). To date, four studies have investigated injuries that occur during rugby sevens matches, the findings of rugby sevens injury data are presented in Table 5.

Fuller et al. (37) investigated 290 players over 578 matches, reporting a total of 104 injuries during international men's rugby sevens matches. Fuller et al. (39) also investigated 930 international men's rugby sevens players over five Sevens World Series from 2008 to 2014, reporting a total of 436 injuries. In addition to the studies by Fuller et al. (37, 39), Lopez et al. (72) examined 1536 players, 868 men and 658 women, over 276 matches and found 48 injuries occurred during American recreational rugby sevens players. A specific analysis was also conducted on concussions during international men's rugby sevens matches by Fuller et al. (38) during 2008 to 2013 over three Sevens World Series with 4086 playing hours. Seventy per cent of injuries were reported to occur in the lower limb, with the most common being to the ankle or knee, joints or ligaments for international players (37). The high relative frequency of ankle and knee, joint or ligament injuries was supported in a study of international men's rugby sevens players that reported lower limb injuries accounted for 63% of injuries with the most common to the ankle or knee, joints or ligaments (39). Possible risk factors for lower limb ligament or joint injuries may be the speed and intensity of rugby sevens along with the high number of changes in direction and side-stepping manoeuvres (37, 78).

In contrast to lower limbs being the most injured body part (37, 39), Lopez et al. (72) found that the head and neck was the most commonly injured body part with 33% of injuries, followed by the upper extremities accounting for 31% for recreational rugby sevens players (72). The variation in the most frequently injured body parts could be a representation of the different tournament levels, with the greater movement patterns performed by international rugby sevens players presenting higher risk factors for lower body injuries. International players also experience more impacts and collisions than recreational players but have fewer head, neck and upper body injuries, suggesting they may be more technically proficient in contact situations. The most common mechanism for injury reported by Lopez et al. (72) was impact with an opposing player, with a tackle accounting for 75% and running contributing to 13% of all injuries. Fuller et al. (37) reported similar results with 34% of

injuries from being tackled, 22% from running and 18% as a result of tackling. Contact situations appear to cause the greatest onset of injuries with Fuller et al. (39) also reporting that 77% of injuries occur due to contact situations.

Concussions occurred 8.3 times per 1000 playing hours for international men's rugby sevens players which was higher than the number of concussions experienced by rugby union players (38). The severity of concussions was also significantly higher for rugby sevens players compared to rugby union, with 19.3 and 10.1 days lost respectively (38). Similar to the injuries reported by Fuller et al. (37, 39) and Lopez et al. (72), tackling was the main cause of concussion in international men's rugby sevens players accounting for 44%, which was higher for backs than compared to forwards (38). The epidemiology of injuries in rugby sevens further reinforces the importance of strength and conditioning programs to limit the level of fatigue and to strengthen body parts at high risk of injuries. Skill acquisition and coaching are also important to ensure appropriate techniques are taught and developed especially around contact and tackling situations.

Table 5: A summary of the injury data from rugby sevens matches.

Study	Participants/ sample size	Number of injuries	Most common body part/ injury	Severity of injury	Cause of injury	Mechanism for injury
Fuller et al. (37)	290 International men 578 matches	104 injuries 106 injuries /1000 playing hours	Most common body part Lower limb 70% Upper limb 18% Most common injury Joint/ ligament 52% Muscle/ tendon 33%	Severe (> 28 days lost) 49% Moderate (8 – 28 days lost) 32%	1 st half 31% 2 nd half 69% Acute onset 93% Gradual onset 7%	Being tackled 34% Running 22% Tackling 18%
Fuller et al. (38)	1128 International men 3 Sevens World Series	34 concussions 8.3 concussions /1000 playing hours		Average 19.3 days lost	1 st half 53% 2 nd half 47% Tournament 1 st day 60% 2 nd /3 rd day 40%	Tackling 44% Being tackled 27%
Fuller et al. (39)	930 International men 5 Sevens World Series	436 injuries 127 injuries /1000 playing hours	Most common body part Lower limb 63% Knee 18%, Ankle 14% Most common injury Joint/ ligament 44% Muscle/ tendon 34%		1 st half 39% 2 nd half 61% Acute onset 91% Gradual onset 9%	Being tackled 32% Tackling 22% Running 19%

Lopez et al. (72)	1536 Recreational 868 Men 658 Women 276 matches	48 injuries 55 injuries /1000 playing hours	Most common body part Head/ neck 33% Upper limb 31% Most common injury Ligament sprains 25% Concussion 15%	Moderate (8 – 28 days lost) 33% Slight (0 – 1 days lost) 25%	1 st half 48% 2 nd half 52% Acute onset 88% Gradual onset 12%	Tackle 75% Running 13%
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Blank spaces within the table indicate that the authors did not report on the specific variable.

Conclusion

There is increasing literature investigating the physical demands of matches for both men's and women's rugby sevens players and injury epidemiology for men's rugby sevens matches. The technical and tactical demands of rugby sevens matches, however still remains poorly understood due to the relative paucity of research in this area. Almost all of the physical and technical demands research into rugby sevens has also concentrated on tournament play, with data on training camps and training practices limited (24, 31, 57). The limited data investigating training practices is somewhat surprising due to the importance of training camps to team preparation for tournaments.

The two studies presented in chapters three and four of the present thesis provides a greater understanding of the physical, technical and tactical demands currently employed during training camps and how the interactions between the physical, technical and tactical demands need to be considered when planning and conducting training sessions. The interactions between the physical, technical and tactical demands are evident where an increase in the physical demands through movement patterns and RPE often results in reductions in skill frequency and or performance (13). Such alterations in skill frequency may reflect a change in tactics employed by the players in order to better resolve the 'problem' posed by the changes in the demands of the training session. By affecting skill frequency or performance, this not only affects the tactics used by the players but it may also reduce the potential for skill acquisition and or the adoption of new tactical approaches. During soccer small sided games investigating the effects of field size, it was demonstrated that as the field size is reduced, players have increased frequency of skills. In contrast to increased frequency of skills with a reduced field size, increasing the field size increases the movement patterns and RPE, with skills performed less frequently (13, 45, 68, 91). Small sided games research highlights the complex interaction that occurs between the physical, technical and tactical demands, with the balance between the physical, technical and tactical demands important for rugby sevens preparation training camps. The two studies of the present thesis begin to address the imbalance in the literature and contribute to existing knowledge on rugby sevens, by quantifying preparation training camps.

Performance Analysis of Sporting Performance

Performance analysis is an emerging area of sports science research and practice, that focuses on the quantification of actual sporting performance in training or competition (48, 81). Performance analysis includes objective measures of sporting performance and aims to

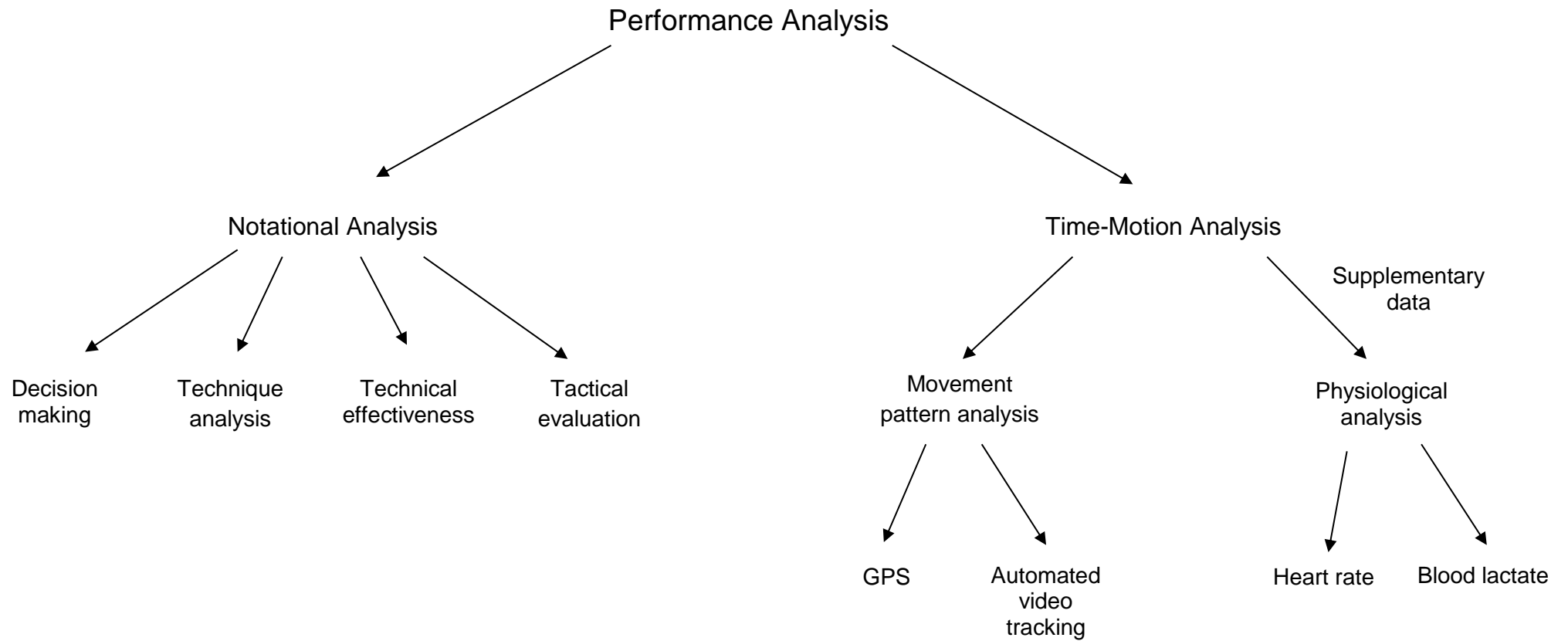
quantify specific key aspects of sporting performance whether it is physical, technical or tactical in nature. Performance analysis is comprised of two important components, time-motion analysis and notational analysis (Figure 1). The terms used in Figure 1 were developed from the work of O'Donoghue (81) and Hughes and Franks (1), that incorporates their ideas surrounding performance analysis and the specific terms. As a result of the work from O'Donoghue (81) and Hughes and Franks (1), they have been considered the pioneers of modern performance analysis.

The analysis of player movement patterns has been considered a part of notational analysis (1), however due to advances in technology it has become a separate component of performance analysis, referred to as time-motion analysis (102). Time-motion analysis reflects a players movement patterns throughout the entirety or portions of a match or training session (102). The analysis of movement patterns provides an understanding of the running activities associated with sporting performance. Movement pattern variables commonly assessed include total distance covered, as well as the distribution of time spent and distances covered in different velocity zones, the number of accelerations, decelerations, sprints and work to rest ratios. With technology such as GPS units and automated video tracking common place in team sport, monitoring GPS variables such as the total distance covered, distribution of time spent and distance covered in different velocity zones, the number of sprints and repeated sprints, the number and magnitude of impacts, accelerations and decelerations, are able to be collected in a far more time efficient manner than was previously available. Physiological analysis reflects the internal effects of exercise on the player's physiological response, with common measures including blood lactate and HR. While blood lactate and HR are technically not a part of time-motion analysis they are supplementary data commonly reported in studies examining physical demands of matches or training (81). Session rating of perceived exertion (sRPE), which is assessed during training camps of the present thesis, is a self-reported variable that indicates the exercise intensity and provides an accurate measure of the individuals response to a particular training load (73).

Notational analysis can be conducted on specific or all aspects of performance including the technique of passing by investigating hand and arm direction at release of the ball or the effectiveness of passing by determining the quality of effective to ineffective passes. Technique analysis can involve a biomechanical or kinesiological analysis of technique, focusing on the key components and the way in which the skill is performed in terms of kinetic and kinematic determinants. Technical effectiveness assesses the outcome of the

key skill being investigated, not the biomechanics of the technique. An example of technical effectiveness relevant to rugby sevens includes assessing passes as successful or unsuccessful (81). Tactical evaluation investigates strategies and plans used by the team, that are often established prior to competition to exploit the oppositions perceived weaknesses and maximise the teams' strengths. Decision making analysis focuses on quantifying players decision making process and the resulting outcomes, to gain a better understanding of the different options available and the chance of success and the risk involved (81) (Figure 1).

Figure 1: Structure of performance analysis and the sub-disciplines.



Validity and Reliability of Global Positioning System (GPS) Units

Introduction to GPS Units

The monitoring of athletic movement patterns has been enhanced with the development of computerised video-based systems and automated multiplayer tracking systems. Multiplayer tracking systems such as GPS units with integrated accelerometers, have enabled the assessment of athletes specific movement patterns (65). Global Positioning System was initially developed by the United States Department of Defence for military use and became fully functional in the mid-1990s (25, 28, 69). Global Positioning System units were first utilised for athlete tracking in 1997 and are now commonly used in team sport settings in both matches and training sessions (25, 101). Global Positioning System is a navigational system that utilises 27 satellites that orbit the earth (69), allowing for the accurate calculations of change in position, distance and speed. Each satellite transmits radio signals about its position and the current time at regular intervals. With the precise measurement of an atomic clock on board the satellites, calculations can be made on the length of time it takes the signal to travel from the satellite to the GPS receiver and thus derive distance between the GPS receiver and satellite (4). The location of the GPS unit is obtained through triangulation once four or more satellite signals are received simultaneously (4, 28, 69). Limitations of GPS include the fact that this system cannot be used indoors, due to the satellite signals required, but also that satellite signals can be influenced by the atmosphere and local obstructions that signals can bounce off. Satellite signals that are interfered with by the atmosphere and local obstructions generate an error in the calculated distance to the satellite and the position and speed of the GPS unit (69).

Recently GPS units have included new technology and software updates, with these improvements allowing for the calculation of additional variables and more reliable software outputs. The introduction of triaxial accelerometers is an example of new technology integrated into GPS units. The accelerometer allows for the measurement of accelerations of the body in three dimensions X, Y, and Z (76). The accelerometer data provides measures on the number and magnitude of impacts, while providing additional accuracy to acceleration and deceleration magnitude and occurrences (77). Along with the new technology of integrated accelerometers in GPS units, advances in software have also allowed GPS units to measure variables more reliably. Both 5 Hz and 10 Hz GPS units, as can be seen in Table 7, were shown to be a reliable measure of athletes' movement patterns including distance covered at LIR, HIR and sprinting, repeated high-intensity efforts and the number of efforts performed at HIR and sprinting (66). The similarities between the 5 and 10 Hz sampling frequencies were attributed to recent updates in software of the 5 Hz units (66).

A limitation of early GPS studies is the use of GPS units with low sampling frequencies, such as 1 Hz (65, 87). It has therefore been argued by Portas et al. (87) that such low sampling frequencies may underestimate the distance travelled at high velocities and with changes of direction, thereby preferentially affecting the validity and reliability of these higher intensity derived outcomes. A higher sampling frequency, therefore would potentially allow for more accurate and reliable GPS data collection (28, 50, 65, 111). In order to understand if GPS is a valid and reliable technology to determine player's movement patterns, a review of the literature was conducted. A summary of the validity and reliability of GPS measures can be seen in Tables 6 and 7, respectively.

Table 6: A summary of the validity of 1 Hz, 5 Hz and 10 Hz GPS units.

Variable assessed	1 Hz	5 Hz	10 Hz
Total distance (m)	Error - 1.8% (22) r = 0.998 (30) MD 0.5 m (74) Bias - 2.0% (50)	CV 2.8%, Bias 1.8% (90) r = 0.64 (65)	CV 1.9%, Bias 0.6% (90)
Distance covered running (m)	SEE 2.6% (87) SEE 2.1%, Bias - 1.0% (86)	Bias - 0.3%, r = 0.77 (111) SEE 2.9% (87) SEE 2.4%, Bias - 3.8% (86)	Bias - 0.2%, r = 0.95 (111)
Distance covered HIR (m)	SEE 31.1%, Bias - 30.8% (10 m) SEE 20.9%, Bias - 16.9% (20 m) SEE 11.3%, Bias - 2.9% (40 m) (62)	CV 7.5%, Bias - 4.0% (90) SEE 27.4%, Bias - 15.0% (10 m) SEE 16.8%, Bias - 11.8% (20 m) SEE 11.5%, Bias - 2.2% (40 m) (62)	CV 4.7%, Bias - 1.1% (90)

Distance covered sprinting (m)	SEE 32.4%, Bias - 37.1% (10 m)	Bias - 0.5%, $r = 0.28$ (111)	Bias - 0.2%, $r = 0.92$ (111)
	SEE 22.3%, Bias - 30.9% (20 m)		
	SEE 12.2%, Bias - 10.1% (40 m) (62)	CV 23.2%, Bias - 17.8% (90)	CV 10.5%, Bias - 7.3% (90)
		SEE 30.9%, Bias - 26.0% (10 m)	
		SEE 17.0%, Bias - 18.6% (20 m)	
		SEE 11.9%, Bias - 6.2% (40 m) (62)	
		CV 8.1% (10 m), 8.1% (20 m), 5.0% (30 m) (114)	
		SEE 5.5%, Bias - 15.3% (20 m)	
		SEE 4.2%, Bias - 10.3% (30 m)	
		SEE 2.9%, Bias - 7.7% (40 m) (86)	
Distance covered with changes of direction (m)	SEE 4.0% (3.5 m/s) (87)	SEE 2.8% (3.5 m/s) (87)	
	SEE 9.6%, Bias - 9.6% (Jog)	SEE 10.2%, Bias - 4.7% (Jog)	
	SEE 11.0%, Bias - 13.9% (Stride)	SEE 10.9%, Bias - 9.4% (Stride)	
	SEE 12.6%, Bias - 19.8% (Sprint) (62)	SEE 11.6%, Bias - 14.4% (Sprint) (62)	
	MD - 1.1 to - 19.6 m, Bias - 6.0% (Walk – Sprint) (50)		

Accelerations (n)		Bias - 9.6%, $r = 0.09$ (1 – 3 m/s/s) Bias - 5.0%, $r = 0.82$ (3 – 5 m/s/s) Bias - 5.2%, $r = 0.5$ (5 – 8 m/s/s) (111)	Bias - 2.9%, $r = 0.98$ (1 – 3 m/s/s) Bias - 3.6%, $r = 0.98$ (3 – 5 m/s/s) Bias - 2.1%, $r = 0.92$ (5 – 8 m/s/s) (111) SEE 0.14 m/s, Bias 0.1 m/s (0 – 2 m/s/s) SEE 0.19 m/s, Bias - 0.04 m/s (2 – 4 m/s/s) SEE 0.32 m/s, Bias - 0.40 m/s (> 4 m/s/s) (2)
Decelerations (n)		Bias 19.3%, $r = 0.83$ (5 – 8 m/s/s) (111)	Bias 8.9%, $r = 0.98$ (5 – 8 m/s/s) (111)
Running speed (m/s)	MD - 0.05 s (1.5 m/s) MD 0.1 s (3.5 m/s) (74) ICC 0.93 (Maximal speed) (8)	CV 9.8% (4.5 m/s), 8.5% (5.5 m/s), 6.6% (6 m/s), 5.7% (7.5 m/s) (114) $r = 0.85$ (Maximal speed) (115)	
Peak speed (m/s)	$r = - 0.47$ (22)	$r = 0.41$ (65)	$r = 0.91$ (64)

Blank spaces within the table indicate that the authors did not report on the specific variable.

% = Percentage, CV = Coefficient of variation, HIR = High-intensity running, Hz = Hertz, ICC = Intraclass correlation coefficient, m = Metre, MD = Mean difference, m/s = Metres per second, m/s/s = Metres per second per second, n = Number, r = Pearson correlation, s = Second, SEE = Standard error of estimate.

Criterion measures used for assessment of GPS validity in Table 6 studies included tape measure (2, 22, 62, 65, 114), radar gun (65), timing lights/gates (8, 22, 62, 64, 65, 74, 86, 114, 115), trundle wheel pedometer (30, 74, 87), stop watch (74), laser (2, 111), internationally certified 400 m athletics track (86), total station EDM / theodolite (50) and radar system (90).

Validity of GPS Units

The general finding from the majority of studies summarised in Table 6 (50, 62, 65, 74, 114) is that the error in GPS units increased with the speed of movement. The error of GPS units with increased movement speed resulted in an underestimation of HIR and sprinting, with this being greater for GPS units operating at lower sampling frequencies including 1 and 5 Hz (50, 62, 65). The monitoring of movement patterns with many rapid changes of direction has also been shown to be less accurate than linear running at the same speed when using GPS units (87). The validity of acceleration measures has been demonstrated to be dependent on the velocity of the acceleration (2, 111). As the magnitude of accelerations increase, the validity of GPS units for quantifying accelerations decreases (2, 111). A 10 Hz GPS unit has been proven to accurately determine accelerations or decelerations that occur and to detect changes in the number of accelerations in a match (111), while a 5 Hz GPS unit may be less accurate in measuring sprints, or accelerations over distances less than 20 m (62).

From the studies that compared sampling frequencies it was concluded that an increase in the sampling frequency did improve the validity of some outcome measures (15, 22, 62, 111). Portas et al. (87) demonstrated that measures of multidirectional running were improved from a standard error of estimate (SEE) of 2.4 – 6.8% to 2.2 – 3.6% with an increased sampling frequency from 1 Hz to 5 Hz respectively. Further improvements in validity with an increased sampling frequency were observed, with a 5.6% improvement in SEE for the distance covered over 20 – 40 m sprints between 1 and 5 Hz GPS units (62). Comparisons of 5, 10, and 15 Hz GPS units demonstrated no significant improvements with increased sampling frequency in the validity and accuracy of measuring movement patterns (113). Similar results were obtained by Johnston et al. (66), who demonstrated that the only significant differences between a 5 and 10 Hz GPS unit were for total distance and peak speed variables.

As determined from the literature review of GPS validity it appears that a 5 Hz GPS unit provides a valid measurement of many movement patterns needed to quantify the physical demands of rugby sevens preparation training camps. However, irrespective of the sampling frequency, GPS units of 5, 10 and 15 Hz have been shown to consistently underestimate HIR and sprinting distances (113), with this as an inherent limitation of GPS units. A 5 Hz GPS unit has been shown to underestimate HIR and sprinting distances over 20 m by 12% and 19% respectively (62). Despite the limitation of GPS it is still the most effective and time efficient device for measuring players movement patterns.

Table 7: A summary of the inter-unit reliability of 1 Hz, 5 Hz and 10 Hz GPS units.

Variable assessed	1 Hz	5 Hz	10 Hz
Total distance (m)	CV 4.0 – 7.2% (22) TEM 5.5% (30)		
Distance covered running (m)	CV 2.2% (50) CV 4.5% (87) CV 1.5% (86)	CV 4.5% (87) CV 6.7%, r = 0.83 (111) CV 1.8% (86)	CV 3.5%, r = 0.94 (111)
Distance covered HIR (m)	CV 11.5 – 30.4 m (22) CV 2.3% (50) CV 58.8% (10 m), 33.3% (20 m), 10.5% (40 m) (62)	CV 33.4% (10 m), 17.5% (20 m), 9.1% (40 m) (62)	

Distance covered sprinting (m)	CV 3.7% (50)	CV 6.3%, $r = 0.22$ (111)	CV 2.0%, $r = 0.96$ (111)
	CV 77.2% (10 m), 44.9% (20 m), 11.5% (40 m) (62)	CV 39.5% (10 m), 23.0% (20 m), 9.2% (40 m) (62)	SEM 10.9% (15 m), 5.1% (30 m) (15)
		CV 1.9% (10 m), 2.1% (20 m), 1.8% (30 m) (114)	
		CV 4.8% (20 m), 3.4% (30 m), 2.3% (40 m) (86)	
Distance covered with changes of direction (m)	CV 5.6% (3.5 m/s) (87)	CV 4.8% (3.5 m/s) (87)	
	CV 8.8% (Jog), 11.5% (Stride), 11.4% (Sprint) (62)	CV 9.3% (Jog), 9.8% (Stride), 8.6% (Sprint) (62)	
Accelerations (n)		CV 16.2%, $r = 0.84$ (1 – 3 m/s/s) CV 9.5%, $r = 0.74$ (3 – 5 m/s/s) CV 11.0%, $r = 0.00$ (5 – 8 m/s/s) (111) CV 5.1% (10 – 30 m) (114)	CV 4.3%, $r = 0.98$ (1 – 3 m/s/s) CV 4.2%, $r = 0.94$ (3 – 5 m/s/s) CV 1.9%, $r = 0.95$ (5 – 8 m/s/s) (111)
Decelerations (n)		CV 31.8%, $r = 0.69$ (5 – 8 m/s/s) (111)	CV 6.0%, $r = 0.99$ (5 – 8 m/s/s) (111)
Running speed (m/s)	CV 1.7% (Maximal speed) (8)	CV 2.1% (4 m/s), 1.9% (5 m/s), 2.0% (5.6 m/s), 1.6% (6.6 m/s) (114)	

Peak speed (m/s)	CV 0.6 – 1.6 m/s (22)	CV 0.8% (114)
	CV 1.2% (8)	

Blank spaces within the table indicate that the authors did not report on the specific variable.

% = Percentage, CV = Coefficient of variation, HIR = High-intensity running, Hz = Hertz, m = Metre, m/s = Metres per second, m/s/s = Metres per second per second, n = Number, r = Pearson correlation, TEM = Typical error of measurement, SEM = Standard error of measurement.

Reliability of GPS Units

Inter-unit reliability of GPS units is reduced with increased changes of direction, speed of movement and running distances of less than 20 m (2, 63, 65, 87). However, an increased sampling frequency does improve reliability of these outcome measures (111). Higher sampling frequencies are also better able to detect the smallest worthwhile change (111), which is important when monitoring player movement patterns over time or investigating the effect of different training programs. Overall, new units, which include a higher sampling frequency generally appear to have greater reliability (22). Beyond a sampling frequency of 15 Hz (a combination of true 5 Hz GPS positioning and algorithm utilising GPS bearing which is a change in position and heading) (71) it is unclear if additional reliability is found with increased sampling frequencies (64). A 10 Hz GPS unit was demonstrated to be a more reliable measure of movement patterns compared to a 15 Hz unit (64). The movement patterns that were more reliable for the 10 Hz sampling frequency included peak speed, distances covered at LIR, HIR and sprinting as well as the number of efforts performed at HIR and sprinting. In addition to a 10 Hz GPS unit being a more reliable measure of movement patterns compared to 15 Hz, both 5 Hz and 10 Hz GPS units have been shown to be a reliable measure of many movement patterns (66). The similarities between the 5 and 10 Hz sampling frequencies were attributed to recent software updates for the 5 Hz units (66).

Another important aspect of GPS reliability is the intra-unit reliability, whereby potential variation in movement patterns exists due to the use of different GPS units of the same model. For a 5 Hz GPS unit the intra-unit variability was demonstrated to be 10% for total distance and HIR distance during match play (63). The 10% intra-unit variability demonstrates that GPS units should not be used interchangeably between players, particularly when analysing high-intensity activities (2, 65). In order to minimise the variability between GPS units, it is recommended that the same unit be used for individual players during training and competition (63, 86). Despite the range of evidence surrounding GPS reliability of different sampling frequencies, a 5 Hz unit appears to provide suitable reliability for collecting data across a range of rugby sevens preparation training camps, however GPS units should not be used interchangeably between players.

Notational Analysis of Technical and Tactical Skills

Notational analysis is an objective measure of the technical and tactical demands of sporting performance, aiming to quantify specific events that occur within a performance in a reliable

and consistent manner (1, 48, 92). Specifically, notational analysis quantifies the frequency and outcomes of key performance indicators that are a combination of actions believed to define specific or broad aspects of a sporting performance (10, 59, 60). Notational analysis through performance indicators can identify the key technical factors that are associated with a specific aspect of sporting performance (118). An example of the key technical factors influencing an aspect of sporting performance may include low body height, strong leg drive and a strong fend for successful ball carries in rugby union (118). Performance indicators of match statistics or general match data on the frequency and execution of skills can highlight the successful and unsuccessful technical and tactical elements of sporting performances (1, 81). Performance indicators are categorised into four types including match classification, technical, tactical and biomechanical indicators. Match classification indicators describe the overall match performance and are interpreted in relation to comparative data of previous performances or the opposition's performance. Technical indicators illustrate the execution of skills through the frequency of success or error of a performance. Tactical indicators define the style and patterns of play by an individual and team in both attack and defence. Biomechanical indicators are used to assess the technique of a specific skill, with analyses involving electromyography, kinetic or kinematic outcomes (60). While biomechanical analyses provide useful data, the frequency of such analyses is typically less than that of match classification, technical and tactical outcomes due to the complexity of biomechanical data collection and analysis.

Performance indicators need to include a combination of multiple sporting aspects and should not be used in isolation as they may not reflect the performance accurately (60). An example of a performance indicator used in isolation would include investigating tackles made, with a high number of tackles believed to indicate a good defensive performance. While such an outcome has some face validity, the inclusion of additional variables such as time in possession, missed tackles and points conceded would better define the defensive performance. In addition to investigating multiple performance indicators, performance indicators may also need to be expressed relative to a predetermined value or as a ratio to normalise the data and enable comparisons between teams, individuals, training sessions and matches. Normalising data could include expressing the number of passes during rugby sevens matches per minute of game time, which would enable comparisons between matches, each half of a match and drills used during training.

The importance of notational analysis is highlighted by the results of Franks et al. (36) who investigated coaches' ability to recall critical events within a sporting performance. It was

found that coaches only recalled 42% of critical events that occurred during the first half of an international soccer match (36), demonstrating the need for objective analysis of sporting performance. Notational analysis was first recorded manually with shorthand codes, a process that was very time-consuming and required substantial learning time. By the mid-1980s, computerised notational analysis systems were designed (92) and the rapid developments in technology since then have enabled notational analysis to become increasingly popular and more reliable. The technological advances improving notational analysis includes the increase in reliability and the complexity of variables assessed due to the capturing of high definition video footage. The ability to record video footage has also enabled lapsed time video analysis, that has been reported to be more reliable than real time analysis during rugby union matches (120).

There are a number of factors that need to be considered when designing a notational analysis system. Initial consultation with experts from that particular sport, including coaching staff, is required so that the system is relevant and applicable to the sport (59, 81). Once research areas have been identified, the next challenge is to determine the feasibility of the methods for collecting the data. Feasibility of collecting data includes the validity, reliability and objectivity at which the particular variables can be recorded (81, 92). It has been demonstrated that 70% of notational analysis studies did not report any reliability measures (60), which raises concerns over the scientific legitimacy of notational analysis and the accuracy of conclusions made in these studies. While notational analysis aims to be an objective measure of sporting performance, any performance analysis that involves human operation will have a degree of subjective classification. In order to minimise the subjective classifications, operational definitions must be established prior to performing the analysis so that each variable is clearly understood (81). With the outcomes assessed during notational analysis of sporting performance varying from match to match, a long-term accumulation of data provides much more reliable and consistent results and allows for the formation of team and player profiles to be established (10, 59). The number of matches or events needed for a profile is dependent on the type of data as well as the athletes and level of competition, where international athletes may be at a level where they exhibit more fixed patterns than recreational athletes (59).

Notational Analysis of Rugby Sevens

With the Australian women's rugby sevens team implementing a decentralised program at the time of data collection, and the importance of preparation training camps for centralised and decentralised programs, the development of technical abilities along with tactical awareness means that appropriate constraints need to be used in training to facilitate the

required outcomes. Appropriate constraints in the learning environment will allow for the development of the desired movement behaviours (16). The constraints that influence the learning process involve an interaction of three factors including individual, environmental and task constraints (48, 83). Individual constraints are internal to the performer and consist of structural factors, which change slowly over time like age, height and body mass and functional, which have a faster rate of change such as fatigue, anxiety and arousal. Environmental constraints are external to the performer and include weather conditions, playing surface and supporters. Task constraints focus on the current tasks and relate to the aim of the task and the rules surrounding that task. Examples of task constraints include drills with the level of defensive pressure being altered or when the coach provides a specific goal such as to maintain possession, or to utilise non-conventional passing options during attacking movements (48).

One of the most important constraints on a team's performance is the level of defensive pressure because of its influence on performance and success (70). Skill performance has been demonstrated to decrease with increasing levels of defensive pressure through a range of sports (70, 82), however when the demands of training are replicated to match activities a transfer of skills exists between training and match performance (32). In order to develop new technical and tactical skills, the progressive use of defensive pressure is essential to the recognition and transfer of the appropriate perceptual information into a match. Identifying the ideal balance between skill development and skill transfer to matches may however, pose some challenges for coaches and players. Specifically, coaches may need to reduce the level of defensive pressure when the players are developing new technical or tactical skills, but at the same time they need to ensure such drills are progressed over time to contested defensive pressure, if these new technical and tactical skills are to transfer to match play. To develop an understanding of the task constraints, chapter four of the present thesis has investigated the effects of varying levels of defensive pressure on the frequency and execution of key attacking skills during international women's rugby sevens training camps.

Conclusion

The literature review was conducted to enable an understanding of the physical, technical and tactical demands required to compete in rugby sevens. Differences were observed between tournament levels with international players maintaining higher movement patterns than their national counterparts. When compared to 15-a-side rugby, rugby sevens forwards

and backs experience relatively similar physical and technical demands during a match, enabling similar training between the positional groups. Successful rugby sevens teams are more efficient in attack, scoring tries with fewer passes and displaying superior defensive skills. The GPS definitions and thresholds used for specific variables within the rugby sevens literature was also investigated to enable comparisons throughout the literature review and the thesis. Unfortunately, there appeared to be quite high variation between some studies in the definitions and thresholds for many GPS variables, making between study comparisons somewhat problematic.

The performance analysis sub-disciplines of time-motion analysis and notational analysis were described and analysed in the literature review as they were the main research paradigms used in chapters three and four. Time-motion analysis was assessed through the use of GPS units, with a summary of the validity and reliability of GPS units across different sampling frequencies presented. A higher sampling frequency of 10 Hz was determined to be the most valid and reliable measure of movement patterns, additionally a 5 Hz GPS unit, that was used in chapter three, provides a valid and reliable measure of many of the movement patterns needed to quantify rugby sevens preparation training camps. It is acknowledged that caution does need to be taken with 5 Hz units as they underestimate HIR and sprinting distances at 20 m by 12% and 19% respectively (62). In addition to the validity of 5 Hz GPS units, for the best reliability it is suggested that GPS units not be used interchangeably between players (62). The field of notational analysis was described and its importance for high performance sport outlined. The focus of the notational analysis section was to review the literature on the key performance indicators, as assessed through notational analysis for rugby sevens. With the use of performance indicators and the development of technical and tactical skills through appropriate constraints, the main task constraint used during game-based drills included the levels of defensive pressure. The literature review aim to provide the appropriate background information to enable understanding of the sport of rugby sevens and the main research paradigms of GPS and notational analysis utilised in the present thesis.

Chapter Three: Quantifying the Movement Patterns of International Women's Rugby Sevens Preparation Training Camp Sessions

Abstract

The aim of the present study was to quantify the movement patterns of preparation training camps for international women's rugby sevens players. A secondary aim was to compare the movement patterns of the four sessions within multiple training camps for international women's rugby sevens players. Twenty four international women's rugby sevens players (age 24 ± 5 years, height 168 ± 5 cm, body mass 68 ± 6 kg; mean \pm SD) were monitored over seven training camps using GPS units with integrated triaxial accelerometers. Training camps consisted of four sessions over two to four days, with a focus on improving the technical and decision making skills in context with team tactics. Women's rugby sevens players covered a median (interquartile range (IQR)) total distance of 3823 (3126 – 4398) m or a relative distance of 2655 (2267 – 3030) m/hour during training camp sessions that lasted a total of 91 (76 – 98) minutes. Women's rugby sevens players also experienced a training load of 389 (295 – 562) arbitrary units (AU) and a relative load of 300 (240 – 360) AU/hour. Total distance consisted of 179 (119 – 253) m or 126 (83 – 168) m/hour of HIR and 50 (24 – 88) m or 35 (18 – 58) m/hour of sprinting. One hundred and twenty five (97 – 149) accelerations occurred during a training sessions with 86 (70 – 103) accelerations occurring per hour. Sprints occurred 41 (29 – 53) times and repeated sprints occurred 14 (8 – 21) times during training camp sessions at a rate of 28 (21 – 36) sprints per hour and 10 (6 – 15) repeated sprints per hour. A significant large effect size increase was observed for the relative training load, accelerations, sprints and repeated sprints from session 2 to 3. A significant large effect size decrease was observed for the absolute training load, total distance, accelerations, decelerations, sprints and repeated sprints from session 3 to 4. The present study indicates that training may not simulate the physical demands of matches or tournaments and that coaches need to monitor the interaction that occurs between the physical, technical and tactical demands in order to maximise tournament performance. To improve or maintain the physiological adaptations, the physical demands during training sessions need to include periods that better match the duration and intensity of rugby sevens matches, with coaches mindful of intermittent breaks during drills.

Introduction

Rugby sevens has increased in popularity, becoming one of the fastest growing sports internationally in recent years (104). The increased popularity of rugby sevens has resulted in its introduction as an Olympic sport at the 2016 Olympic Games in Rio de Janeiro, Brazil. Rugby sevens is a variation of traditional rugby union, played on a full-size rugby field with teams made up of seven players, three forwards and four backs. Matches consist of seven-minute halves with a two-minute half-time interval. The format of rugby sevens matches means an entire tournament can be played over two to three consecutive days, with teams playing multiple games each day, with a minimal recovery of approximately three hours between matches (78). The international tournament structure appears to result in considerable fatigue and muscle damage, with muscular power reduced by 26% at the conclusion of a two day tournament (116). Rugby sevens involves frequent intermittent bouts of high-intensity activity interspersed with short recovery periods (55). The anaerobic nature of rugby sevens is demonstrated through the high number of sprints and accelerations performed by each player per match (88). In addition to the high number of sprints and accelerations, rugby sevens players covered total distances of approximately 1500 m at an intensity of 100 m/min (18, 88). Rugby sevens match analysis (55, 88, 103) demonstrated that rugby sevens players require high levels of aerobic and anaerobic fitness to sustain the high movement patterns.

During the 2012 – 2013 international season, the Australian women's rugby sevens program was decentralised with semi-professional players. In order to transition from semi-professional to a more professional player preparation structure and prepare for the 2016 Olympic Games, almost all the core teams of the World Rugby Women's Sevens Series including Australia, Canada, China, England, Fiji, France, Russia, South Africa, Spain and the USA have programs that are now centralised, with the exception of New Zealand that maintains a decentralised program (21). While Australia and the other core teams in World Rugby Women's Sevens Series now have centralised programs, these centralised programs are newly developed and may only have 16 contracted players for a 12 member squad for each tournament, with injury or loss of form requiring additional players to be introduced for training camps and tournaments. While the core teams of the Women's Sevens Series are centralised, the qualifying teams who play-off for a spot in each round of the series, still have decentralised programs making training camps an important part of team preparation (21). National championships are also played in many of the Women's Sevens Series core countries including Australia, in order to develop and identify talent for international tournaments. The players that represent their state in the national championships are semi-

professional athletes living in a variety of locations, who use training camps to prepare for competition.

Training camps are organised to prepare teams for upcoming competitions with a focus on improving technical and decision making skills in context with team tactics. The interaction between the physical, technical and tactical demands of training is important for the coaching and sports science staff to understand, if competition performance is to be optimised. Alterations in skill frequency and or performance, such as a reduced frequency in skills and level of execution, have been demonstrated with increased physical demands of movement patterns and RPE (45, 68). The focus on technical and tactical demands of preparation training camps would suggest that the monitoring of movement patterns during training camps is important for rugby sevens players. The monitoring of players movement patterns would better allow the coaching staff to determine if the players are being exposed to training loads of sufficient intensity and duration, that in some way replicate the demands of matches and tournaments, but at the same time do not excessively increase the risk of injury or overtraining.

To date, three studies have investigated rugby sevens training (24, 31, 57), however no studies have quantified the movement patterns of training camps for either men's or women's rugby sevens players and how the sessions within these camps may be designed with respect to the movement patterns performed by the players. The primary aim of the present study, therefore was to quantify the movement patterns of preparation training camps for international women's rugby sevens players. A secondary aim was to compare the movement patterns of the four sessions within multiple training camps for international women's rugby sevens players.

Methods

Experimental Approach to the Problem

An observational study was undertaken to quantify the movement patterns of international women's rugby sevens players during preparation training camps within an international season. All the players were a part of the Australian national women's rugby sevens squad. The training camps were undertaken from March to June prior to the 2013 Women's Sevens World Cup.

Subjects

Twenty four international women's rugby sevens players (age 24 ± 5 years, height 168 ± 5 cm, body mass 68 ± 6 kg; mean \pm SD) participated in the present study over a total of seven training camps. The training camps occurred over a period of four months in the course of one international season, with each training camp conducted over a period of two to four days. The number of players analysed in each training session ranged from seven to 11 (Table 8). Data were collected from 28 training sessions, with 252 GPS files analysed. Results were reported for players who were free from injury and illness during training camps and who completed every session within an individual training camp. All players were informed of the benefits and risks of participating in the present study, the participant information form that was provided to the players is presented in Appendix 1. All players provided written informed consent, with the team manager providing written consent for players less than 18 years of age (Appendix 2). The present study was approved by the Bond University Human Research Ethics Committee (BUHREC).

Table 8: A summary of the schedule and analysed data of women's rugby sevens preparation training camps and tournaments.

	Day 1		Day 2		Day 3		Day 4		
	am	pm	am	pm	am	pm	am	pm	
Training camp/ Tournament (Date)									Number of players analysed
1 (7 th – 10 th March 2013)		X*	X*	X*	X*	X	X		8
IRB Women's Sevens World Series - Guangzhou, China (30 th – 31 st March 2013)									
2 (20 th – 21 st April 2013)	X *	X*	X*	X*					10
3 (26 th – 28 th April 2013)		X*	X*	X*	X*	X			9
4 (4 th – 6 th May 2013)		X*	X*	X*	X*	X			7
IRB Women's Sevens Challenge Cup - London, England (12 th – 13 th May 2013)									
IRB Women's Sevens World Series - Amsterdam, Netherlands (17 th – 18 th May 2013)									
5 (27 th – 30 th May 2013)		X*	X*	X*	X*	X	X		8
6 (12 th – 13 th June 2013)	X*	X*	X*	X*					10

3	7 (18 th – 21 st June 2013)	X*	X*	X*	X*	X	11
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IRB Women's Rugby Sevens World Cup - Moscow, Russia (29th – 30th June 2013)

X represents scheduled team sessions that were conducted during training camps,* indicated the training session data that were analysed.

Training Camps

The first four sessions of every training camp were selected for analyses due to the varying structure of the sessions within a training camp. The first four sessions of a training camp consisted of physical, technical and tactical preparation through on-field training, while additional sessions, if performed, consisted of recovery days or technical and tactical team sessions involving video review and team discussions (Table 8). All on-field training camp sessions included technical and decision making skills in context with team tactics. Every training camp had at least four sessions, that allowed for the most amount of training sessions across training camps to be analysed. By analysing multiple training camps and grouping the sessions together, the present thesis sought to gain a more global and representative data source from the training camps. The duration of a training session was analysed, that included the periods of time in between drills or during drills where inactivity occurred for coaches to provide the appropriate feedback, instructions and explanation or for drinks breaks to be taken. The disruptions or breaks in activity were included to reflect the actual physical demands of the training sessions. By excluding all the breaks during the training sessions, this would have depicted an inaccurate representation of the physical demands performed during sessions of a training camp. Previous studies examining training drills have also used the present approach (51, 57).

Global Positioning System

The present study performed movement pattern analysis using GPS units (SPI Pro, GPSports Systems, Canberra, Australia) sampling at 5 Hz. The GPS units also contained an integrated triaxial accelerometer sampling at 100 Hz. The GPS units used in the present study, have been reported to be valid and reliable in assessing many movement patterns. A coefficient of variation (CV) of 5 – 8% and 1.8 – 2% was demonstrated for the validity and reliability, respectively for the distance covered sprinting over 10 – 30 m (114). Additional validity and reliability of GPS movement patterns is presented in Tables 6 and 7, respectively. The GPS units were activated approximately 15 minutes before the training session to allow the satellites to synchronise with the units, as per the manufacturer's recommendations. Prior to the training session commencing the GPS units were positioned between the scapulae, at the approximate level of the first thoracic vertebrae, using an elastic vest worn underneath training attire. All players were familiar with the data collection procedures and had previously worn the units during training sessions. Global Positioning System data were analysed from the start of training, defined by the end of the individual stretching phase of the warm up. After each training session the GPS data were downloaded using Team AMS v2014.3 (GPSport System) software.

Key outcomes from the GPS data included, total distance covered, distances covered at HIR and sprinting, the number of accelerations, decelerations, sprints and repeated sprints. The velocity zones have previously been used in other rugby sevens studies and included HIR (5 – 6 m/s) and sprinting (> 6 m/s) (55, 57). The velocity zones used in the present study were based on men's rugby sevens studies, that are consistent with the vast majority of the literature for women's rugby sevens players (26, 88, 104). The use of men's rugby sevens velocity zones has been shown to underestimate HIR and sprinting distances (18), however this approach was selected to allow direct comparisons between the data of the present study and the majority of the rugby sevens literature. Accelerations and decelerations were classified as > 1 m/s/s and < - 1 m/s/s respectively, for a minimum of 1 second (2, 57). A sprint effort was defined as an acceleration > 2.5 m/s/s or velocity > 6 m/s for a minimum of 1 second. If the movement included both criteria then it was counted as only one sprint (29). A repeated sprint was defined as a sprint effort, as described above, that occurred two or more times within 30 seconds (8). Global Positioning System data were present as both absolute and relative movement patterns. Relative movement pattern data were presented per hour as opposed to per minute, as has been commonly done in rugby sevens match research (57, 103). Data were presented per hour during training camps, due to the reduced frequency of movement patterns and the extended duration of training sessions compared to matches. Data presented per hour allowed for comparisons between training sessions of different durations.

Session Rating of Perceived Exertion and Training Load

The subjective internal load on players was assessed by sRPE, whereby a score of one was considered very easy and a score of 10 as maximal effort (19, 23). Session rating of perceived exertion was collected approximately 30 minutes after each training session to reflect the entire session, rather than the most recent exercise intensity (14, 19). All players were familiar with the data collection procedures and had previous experience with sRPE. Training load, measured in AU was established for all players through the following equation: Training session duration (min) x sRPE (14, 19).

Statistical Analysis

Descriptive statistics (median, IQR) were reported to characterise the absolute and relative movement patterns of rugby sevens training camps as normality and sphericity assumptions were not met at the session level for any outcome measures. As a number of data transformations did not improve non-normality, the non-parametric alternative Friedman ANOVA was used with statistical significance set at $p < 0.05$. Significant Friedman tests

were followed by Wilcoxon signed ranked tests to complete post-hoc pairwise comparisons of the sessions. A Bonferroni correction ($p = 0.05 / 6$) was applied to the analysis and effects were reported at $p < 0.008$ level of significance, to reduce type one errors resulting from the six comparisons conducted between the four sessions. Effect sizes were calculated using significant Wilcoxon signed ranked test comparisons of the sessions with the following equation: $r = \frac{z}{\sqrt{N}}$, where z is the z-score and N is the number of observations. Effect size differences were assessed based on small (0.1 – 0.29), medium (0.3 – 0.49) and large (≥ 0.5) (33, 94). All statistical analysis was performed using SPSS (version 20, SPSS Inc. Chicago, USA).

Results

Women's rugby sevens players covered a median (IQR) total distance of 3823 (3126 – 4398) m and experienced a training load of 389 (295 – 562) AU during training camp sessions that lasted for a duration of 91 (76 – 98) minutes. Total distance consisted of 179 (119 – 253) m of HIR and 50 (24 – 88) m of sprinting. An average training session consisted of 125 (97 – 149) accelerations, 103 (82 – 123) decelerations, 41 (29 – 53) sprints and 14 (8 – 21) repeated sprints. There was a significant difference between the sessions for the absolute training load ($\chi^2(3) = 12.8, p = 0.005$), total distance covered ($\chi^2(3) = 9.5, p = 0.023$), number of accelerations ($\chi^2(3) = 29.7, p < 0.001$), number of decelerations ($\chi^2(3) = 14.7, p = 0.002$), number of sprints ($\chi^2(3) = 35.4, p < 0.001$) and the number of repeated sprints ($\chi^2(3) = 23.5, p < 0.001$). In contrast, there were no significant differences in the distances covered at HIR ($\chi^2(3) = 7.2, p = 0.063$) and sprinting ($\chi^2(3) = 5.9, p = 0.116$) velocities between the sessions. A significant large effect size decrease was observed for training load ($z = -3.68, p < 0.001, r = -0.50$), total distance ($z = -4.35, p < 0.001, r = -0.55$) as well as the number of accelerations ($z = -6.17, p < 0.001, r = -0.78$), decelerations ($z = -4.65, p < 0.001, r = -0.59$), sprints ($z = -5.98, p < 0.001, r = -0.75$) and repeated sprints ($z = -5.06, p < 0.001, r = -0.64$) from session 3 to 4. The absolute number of sprints ($z = -3.36, p = 0.001, r = -0.42$) and repeated sprints ($z = -3.24, p = 0.001, r = -0.41$) had a significant medium effect size increase from session 2 to 3. A significant medium effect size decrease was observed between sessions 2 and 4, for the absolute number of sprints ($z = -3.13, p = 0.002, r = -0.39$) and repeated sprints ($z = -2.64, p = 0.008, r = -0.33$). Sprints ($z = -3.54, p < 0.001, r = -0.44$) and repeated sprints ($z = -3.83, p < 0.001, r = -0.48$) also significantly decreased with a medium effect size from session 1 to 4. The absolute GPS data for an average session and individual sessions of women's rugby sevens training camps are summarised in Table 9.

Table 9: Comparison of the absolute GPS data between an average session and individual sessions of women's rugby sevens training camps.

	Average session	Session 1	Session 2	Session 3	Session 4
Duration (min)	91 (76 – 98)	90 (68 – 97) ^{a***}	96 (90 – 98) ^{c***}	94 (78 – 104) ^{c**}	76 (72 – 94)
Training load (AU)	389 (295 – 562)	380 (270 – 564)	403 (322 – 548)	470 (366 – 654) ^{c***}	312 (234 – 460)
Total distance (m)	3823 (3126 – 4398)	3819 (3256 – 4419)	3882 (3319 – 4420)	3931 (3317 – 4663) ^{c***}	3560 (2672 – 4217)
Distance covered HIR (m)	179 (119 – 253)	180 (80 – 248)	184 (145 – 244)	195 (129 – 269)	158 (89 – 250)
Distance covered sprinting (m)	50 (24 – 88)	52 (16 – 94)	58 (31 – 87)	49 (21 – 93)	44 (16 – 80)
Accelerations (n)	125 (97 – 149)	129 (101 – 151)	125 (101 – 148)	129 (110 – 160) ^{c***}	106 (84 – 131)
Decelerations (n)	103 (82 – 123)	106 (86 – 123)	105 (85 – 122)	104 (90 – 134) ^{c***}	96 (69 – 116)
Sprints (n)	41 (29 – 53)	41 (30 – 60) ^{c**}	39 (30 – 46) ^{b**, c**}	47 (40 – 57) ^{c***}	30 (26 – 41)

Repeated sprints (n)	14 (8 – 21)	15 (7 – 27) ^{c**}	13 (9 – 19) ^{b**, c**}	17 (12 – 27) ^{c***}	10 (7 – 15)
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Data are presented as median and interquartile range, ^a = significant difference compared to session 2, ^b = significant difference compared to session 3, ^c = significant difference compared to session 4. Magnitude differences were identified by * small, ** medium and *** large effect sizes. AU = Arbitrary units, HIR = High-intensity running, m = Metre, min = Minute, n = Number.

Women's rugby sevens players covered a median (IQR) relative distance of 2655 (2267 – 3030) m/hour and experienced a training load of 300 (240 – 360) AU/hour during an average training camp session. High-intensity running consisted of a relative distance of 126 (83 – 168) m/hour and 35 (18 – 58) m/hour of sprinting. Typically each training session had 86 (70 – 103) accelerations, 72 (58 – 86) decelerations, 28 (21 – 36) sprints and 10 (6 – 15) repeated sprints per hour. There was a significant difference between the sessions for the relative distance covered ($\chi^2(3) = 10.1$, $p = 0.017$), training load ($\chi^2(3) = 7.4$, $p = 0.027$) as well as the number of accelerations ($\chi^2(3) = 12.1$, $p = 0.007$), decelerations ($\chi^2(3) = 8.2$, $p = 0.041$), sprints ($\chi^2(3) = 17.6$, $p < 0.001$) and repeated sprints ($\chi^2(3) = 17.3$, $p = 0.001$).

During all sessions of a training camp, there was no significant difference in the relative distances covered in HIR ($\chi^2(3) = 1.9$, $p = 0.596$) and sprinting ($\chi^2(3) = 0.3$, $p = 0.954$). A significant large effect size increase was observed for relative training load ($z = -3.85$, $p < 0.001$, $r = -0.50$) as well as the number of accelerations ($z = -3.75$, $p < 0.001$, $r = -0.55$), sprints ($z = -4.89$, $p < 0.001$, $r = -0.62$) and repeated sprints ($z = -4.23$, $p < 0.001$, $r = -0.53$) from session 2 to 3. Training load ($z = -3.04$, $p = 0.002$, $r = -0.41$) and the number of sprints ($z = -3.18$, $p = 0.001$, $r = -0.40$) and repeated sprints ($z = -3.41$, $p = 0.001$, $r = -0.43$) significantly decreased with a medium effect size between sessions 3 and 4. A significant medium effect size decrease was observed for the number of sprints ($z = -2.90$, $p = 0.004$, $r = -0.37$) between sessions 1 and 2 and repeated sprints ($z = -2.86$, $p = 0.004$, $r = -0.36$) from session 1 to 4. The relative GPS data for an average session and individual sessions of women's rugby sevens training camps are summarised in Table 10.

Table 10: Comparison of the relative GPS data between an average session and individual sessions of women's rugby sevens training camps.

	Average session	Session 1	Session 2	Session 3	Session 4
Duration (min)	91 (76 – 98)	90 (68 – 97)	96 (90 – 98)	94 (78 – 104)	76 (72 – 94)
Training load (AU/hour)	300 (240 – 360)	240 (180 – 360)	240 (180 – 300) ^{b***}	300 (240 – 420) ^{c**}	240 (240 – 300)
Relative distance (m/hour)	2655 (2267 – 3030)	2566 (2179 – 3264)	2550 (2180 – 2892)	2717 (2375 – 3007)	2789 (2227 – 3067)
Distance covered HIR (m/hour)	126 (83 – 168)	121 (73 – 160)	125 (86 – 160)	141 (90 – 171)	124 (79 – 177)
Distance covered sprinting (m/hour)	35 (18 – 58)	33 (13 – 63)	37 (20 – 56)	35 (14 – 60)	35 (17 – 56)
Accelerations (n/hour)	86 (70 – 103)	88 (69 – 112)	80 (64 – 97) ^{b***}	90 (74 – 108)	89 (65 – 102)
Decelerations (n/hour)	72 (58 – 86)	72 (61 – 89)	69 (51 – 78)	73 (58 – 88)	77 (58 – 88)
Sprints (n/hour)	28 (21 – 36)	33 (22 – 39) ^{a**}	25 (19 – 31) ^{b***}	32 (27 – 38) ^{c**}	27 (18 – 35)

Repeated sprints (n/hour)	10 (6 – 15)	12 (5 – 17) ^{c**}	8 (5 – 12) ^{b***}	12 (8 – 17) ^{c**}	8 (5 – 12)
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Data are presented as median and interquartile range, ^a = significant difference compared to session 2, ^b = significant difference compared to session 3, ^c = significant difference compared to session 4. Magnitude differences were identified by * small, ** medium and *** large effect sizes. AU = Arbitrary units, HIR = High-intensity running, m = Metre, min = Minute, n = Number.

Discussion

The monitoring of movement patterns during training sessions is important for rugby sevens because of the limited number of days to prepare a team for competition during training camps. Preparation training camps are organised to prepare teams for upcoming competition, with a focus on improving the technical and decision making skills in context with team tactics. By quantifying the movement patterns of women's rugby sevens training camps, the present data provides an understanding of the absolute and relative movement patterns of training camps. An understanding of the movement patterns are important for coaching and sports science staff, whose primary aim is to control the complex interaction between the physical, technical and tactical demands of training camps, minimising the risk and optimising training by reducing player injury and overtraining and maximising player performance at upcoming competitions.

A median (IQR) total distance of 3823 (3126 – 4398) m or a relative distance of 2655 (2267 – 3030) m/hour was covered during an average women's rugby sevens training session. Rugby sevens players have been shown to cover distances of 1500 m at an intensity of 100 m/min (6000 m/hour) during rugby sevens matches (98, 103-105). The reduced relative distance observed during training sessions compared to rugby sevens matches, reported in the present study was to be expected for several reasons. Some of the differences between rugby sevens matches and the training sessions analysed during preparation training camps may be explained by the intermittent breaks that occurred within training sessions, where coaches provided feedback, instructions and explanations or when the players' had drinks breaks. Coaches, therefore need to be aware of the number and duration of these breaks, if they believe the physical demands of these training sessions are insufficient to simulate match conditions and promote physiological adaptations.

The duration of 91 (76 – 98) minutes for an average training camp session is substantially more than the game time of rugby sevens matches, 14 minutes and 20 minutes for finals. Substantially greater training than game duration is quite unlike most other team sports, where the training duration more closely matches game time (46, 79). The greater duration of rugby sevens training sessions compared to matches would appear sensible, as the coaching staff need the additional time with the team together in order to develop technical and tactical skills. However, as a result of the technical and tactical focus of training camps and the intermittent breaks in training resulting from coaches feedback and drinks breaks, the overall physical demands of the training sessions, when considered as a whole may appear insufficient to enhance or maintain physiological adaptations. While a two to four day

camp may not substantially contribute to detraining of the players, seven training camps occurred over four months, with each training camp requiring many of the players to travel large distances, meaning that additional training days may have been lost before and after each training camp. Therefore, if each training camp provided insufficient physical stimulus, this could have a negative effect on the players' physical conditioning over the course of the season (9). Training sessions and any movement patterns performed outside of training camps was not accounted for during the present study, with the coaching staff potentially requiring players to undertake conditioning sessions outside of the analysed training camps. It is important that coaches are aware that if training camps are focusing on technical and tactical skills that the physical demands still need to be maintained, if detraining of the players physical conditioning is to be prevented.

The total training load for an average training camp over three days with four training sessions was 1701 AU. Elloumi et al. (31) observed training load of 1763 AU during week eight of a reduced training period for international men's rugby sevens players. Week eight, the final week of the training program was chosen because similar to training camps of the present study, the focus was on team preparation for upcoming tournaments (31). While the training load values found in the present study and Elloumi et al. (31) appear very similar, differences in the study design may affect direct comparisons between the two studies. The study by Elloumi et al. (31) involved not only physical conditioning and technical and tactical development but included strength training in the overall training load. In addition to the differences in training modes included in the calculation of training load, the present study consisted of four sessions with a median duration of 91 minutes compared to Elloumi et al. (31) week eight training program consisting of seven sessions with an average duration of 60 minutes. The differences in training mode, number of sessions and duration somewhat limits the comparisons that can be made between the training loads reported in these studies.

From a physical conditioning perspective, an average training session for women's rugby sevens training camps may have been more beneficial and addressed specificity of training, if the training sessions were shorter in duration and more intense. However, due to rugby sevens programs being newly centralised or still utilising a decentralised program, training camps are required to prepare players technical and tactical skills as a team for tournaments. With the primary focus of preparation training camp sessions being technical and tactical skill development, some of the drills performed in these training sessions would need to be done at a higher intensity. Coaches need to ensure that the training sessions include sufficient periods, where the physical demands are developed in conjunction with the

technical and tactical skills. One possible solution to this potential conundrum of how to effectively develop the physical, technical and tactical skills, is to use game-simulation drills and small sided games. Small sided games allow for the simulation of movement patterns performed in a game, as well as having players performing technical, tactical and decision-making skills under pressure and fatigue (13, 35, 41-43, 47, 58). Game-simulation drills replicating match-like conditions, have also been demonstrated to be more physically and cognitively demanding than performing closed skill refining drills (32).

Increases in the relative training load from session 2 to 3 for rugby sevens players was accompanied with increases in the relative number of accelerations, sprints and repeated sprints. In addition to the increases in relative movement patterns from session 2 to 3, absolute and relative training load decreased from session 3 to 4, as did the total distance and the absolute number of accelerations, decelerations, sprints and repeated sprints. Variations in both the absolute and relative training load during rugby sevens training camps may be explained in part by the findings of Casamichana et al. (14). High-intensity efforts such as accelerations, decelerations, sprints and repeated sprints were shown to be some of the factors that influence sRPE and therefore training load (14). Accelerations, decelerations, sprints and repeated sprints have been shown to be more energetically demanding than running at a constant velocity, imposing a greater internal load on players (85, 110). As a result of high-intensity efforts including accelerations, decelerations, sprints and repeated sprints being more energetically demanding, it would suggest that differences in the frequency of high-intensity efforts across training sessions of a training camp, reflect a systematic periodised structure developed by the coaching staff. The periodisation model appeared to involve an increase in training load, resulting from a greater frequency of high-intensity efforts, from session 2 to 3 and a reduction in these variables from session 3 to 4. The absolute and relative HIR and sprinting distances performed during training camps, did not substantially change over the sessions of training camps. The lack of differences in the distances covered during HIR and sprinting between sessions during training camps, may have reflected a consistent requirement to perform HIR and sprinting in all drills and sessions.

Monitoring training camps could assist coaching and sports science staff with understanding and controlling the complex interaction between the physical, technical and tactical demands of training sessions. Men's rugby sevens training analysis demonstrated that low-intensity, skill refining drills were least representative of the demands of rugby sevens matches (57). However, the skill refining drills are still considered important aspects of training camp

sessions, as they allow the progressive development of complex technical and tactical skills. By quantifying the movement patterns of women's rugby sevens training camps, the present data provides an understanding of the absolute and relative movement patterns of training camps, where the focus is on technical and tactical skill development. Quantifying the movement patterns of training sessions is vital if the coaches are to balance the somewhat conflicting interaction between the physical, technical and tactical demands of training sessions, when trying to ensure optimal team performance at upcoming tournaments.

Conclusion

In conclusion, the present study quantified the movement patterns of women's rugby sevens training camps. Training camps for decentralised rugby sevens programs, uncontracted players being introduced into a centralised program or state level players coming together to compete in national championships, play an important role in the development of technical and tactical skills as a team. Managing the complex interaction between the physical, technical and tactical demands is important and in order to balance the two objectives the monitoring of training camps is needed.

The data collected during the present training camps demonstrated that as a result of the technical and tactical focus of training camps, the physical demands may be insufficient to enhance or maintain physiological adaptations. The focus on technical and tactical skill development throughout training sessions means that coaches need to be aware of the potential for physical detraining, highlighting the importance of monitoring the physical demands of training sessions. To improve or maintain the physical capacities required for tournament success, the physical demands during training sessions need to address specificity of training by including training drills that better match the duration and intensity of rugby sevens matches. The frequency and duration of breaks in activity are also important factors that may contribute to the relative lack of intensity of training sessions, indicating coaches need to be aware of these breaks when physical demands are to be maximised. Between session comparisons demonstrated that increases occurred in the high-intensity variables such as the number of accelerations, decelerations, sprints and repeated sprints from session 2 to 3, with many of these variables and training load being reduced from session 3 to 4. The alterations in the high-intensity movement patterns may indicate a systematic periodised structure, whereby the coaching staff sought to increase the relative movement patterns of session 3 and reduce the absolute demands of session 4. The results reported in the present study suggest that the regular monitoring of training camp movement

patterns could assist coaching staff to better quantify the periodisation of the physical, technical and tactical demands within training camps. The regular monitoring of training would better allow coaches to ensure that training sessions and camps address the technical and tactical skills as well as the physical demands required for competition.

Chapter Four: Effect of Defensive Pressure on International Women's Rugby Sevens Attacking Skills Frequency and Execution

Abstract

The aim of the present study was to determine the effects of the level of defensive pressure on the frequency and execution of key attacking skills for international women's rugby sevens players during training camps. Performance analysis was conducted on 42 preparation training camp drills during the 2012 – 2013 international women's rugby sevens season. Training camp sessions were recorded using a video camera and only the attacking team's performance was analysed during game-based drills. All game-based drills were conducted using the full field with seven attacking players and seven defensive players except for the no defence constraint. Manual notational analysis was performed in lapsed time with video software used to view the footage. Skill outcomes assessed included pass type, pass accuracy, catching, evasive moves and line breaks. The present study found that defensive pressure had a significant effect on pass type, evasive moves and line breaks ($p < 0.05$), but no significant effect on the passing accuracy and catching ability of players ($p > 0.05$). A cut-out pass (standard residual (SR) = 3.3) and switch pass (SR = 3.7) were more likely to happen than expected by chance during no defence and uncontested defence respectively. An offload was less likely to happen than expected by chance during uncontested defence (SR = - 2.2), but more likely to occur than expected by chance during contested defence (SR = 9.6). No defence had the most accurate passing with 60% good accuracy compared to 55% during contested defence. A line break (SR = 4.7) and a swerve (SR = 2.5) were more likely to happen than expected by chance during contested defence. Coaches should progressively overload the degree of defensive pressure during training and alter the constraints, instructions and or feedback to encourage the performance of non-conventional passes under contested defensive pressure that are required for success in matches and tournaments. The interaction between the physical, technical and tactical demands should also be monitored in order to understand how altering the physical demands imposed on the players influences the frequency and execution of key attacking skills.

Introduction

Rugby sevens has increased in popularity recently due to the inclusion of both men's and women's rugby sevens in the 2016 Olympic Games in Rio de Janeiro, Brazil. Rugby sevens

is played under almost identical rules and on the same size field as rugby union. In contrast to rugby union, rugby sevens consists of teams made up of seven on-field players, three forwards and four backs. Matches consist of seven-minute halves with a two-minute half-time interval (49, 104). The greater space available for rugby sevens compared to rugby union players, is likely to create different technical and tactical demands, whereby rugby sevens players will have more possessions of the ball and need to make more game decisions per unit of time (54).

Higher ranked teams in international men's rugby sevens tournaments have demonstrated superior technical skills, that allow for greater ball retention and efficiency in attack (54). Internationally successful men's rugby sevens teams maintain greater time in possession of the ball compared to less successful teams (61), however an increased possession time per try was associated with worse team rankings during men's sevens series (52). In addition to increased possession time per try being associated with worse team rankings, more passes per try were also associated with worse rankings during international tournaments (54). Efficiency in attack through less possession time and passes per try seems to be an effective attacking outcome, with Hughes et al. (61) providing additional insight into how successful teams are efficient in attack. Successful teams had fewer conventional and loop passes and more cut-out and dummy passes (61). Non-conventional passes may be considered more complex (defined as the number of parts or components in the amount of information processing demands that characterise skill) (75) and impose additional decision making challenges on the defensive team. Attacking teams that have the technical and tactical skills to use non-conventional passes are more likely to attack with greater efficiency and have a higher probability of winning matches and tournaments. By quantifying a number of technical skills contributing to attacking efficiency, this may enable the development of improved training practices and assist with improving players' attacking technical and tactical skills.

In order to transition from a semi-professional, decentralised program to a more professional player preparation structure and prepare for the 2016 Olympic Games almost all the core teams of the World Rugby Women's Sevens Series including Australia, Canada, China, England, Fiji, France, Russia, South Africa, Spain and the USA have programs that are now centralised, with the exception of New Zealand that maintains a decentralised program (21). Despite centralised programs for Australia and the other core teams in the World Rugby Women's Sevens Series, preparation training camps still play an important role. The newly developed centralised programs may only have 16 contracted players for a 12 member squad for each tournament, with injury or loss of form requiring additional players to be

introduced for training camps and tournaments. The qualifying teams for the Women's Sevens Series, that play-off for a spot in each round of the series still have decentralised programs making training camps an important part of team preparation (21). National championships played in many of the Women's Sevens Series core countries including Australia, use the competition to develop and identify talent for international tournaments. The players that represent their state in the national championships are semi-professional athletes living in a variety of locations, that utilise training camps to prepare for competition.

Preparation training camps are used to reduce the decentralisation challenges and the introduction of additional players for tournaments, by providing the opportunity for women's rugby sevens players to train together and develop the necessary technical skills and tactical awareness. Training camps primary focus is the development of technical and decision making skills in context with team tactics. The development of technical and tactical skills during training camps means that appropriate constraints need to be utilised in the learning environment for the development of the desired movement behaviours (16). One of the most important constraints on a team's sporting performance is the level of defensive pressure (70). Increased defensive pressure has been demonstrated to result in acute decreases in ball accuracy of attacking players during a soccer cross (82) and field goal shooting percentage in basketball (70). However, if all training drills are performed with no or uncontested defensive pressure, it is unlikely the team will be able to perform optimally during competition, where the level of defensive pressure is the most difficult. A gradual progression of defensive pressure may allow the players to become better attuned to the key perceptual information, thereby increasing the probability of producing the appropriate decision and skill execution during the game (16, 83). When training drills progressively become more representative of competition, a positive transfer of skill execution is more likely to be evident between practise and match performance (32, 83). In order to develop the technical skills and ensure that the players can perform these skills under the defensive pressure of competition, the interaction between the physical, technical and tactical demands also needs to be monitored during training.

To date there are no published data available that describe the technical and tactical skills of women's rugby sevens players and how the degree of defensive pressure influences these outcomes. The primary aim of the present study therefore, was to determine the effects of the level of defensive pressure on the frequency and execution of key attacking skills for international women's rugby sevens players during training camps.

Methods

Experimental Approach to the Problem

An observational study was undertaken to determine the effects of the level of defensive pressure on the frequency and execution of key attacking skills for international women's rugby sevens players. The training camps in the present study were collected from March to June prior to the 2013 Women's Sevens World Cup tournament.

Subjects

The study included 24 international women's rugby sevens players (age 24 ± 5 years, height 168 ± 5 cm, body mass 68 ± 6 kg; mean \pm SD) that were all a part of the same international team. All players present during training camps were deemed to be the best players in Australia, as determined by the coaching staff and as such these players had relatively similar skill levels. Performance analysis was conducted on 42 preparation training camp drills during the 2012 – 2013 international women's rugby sevens season. The training drills were recorded over seven preparation training camps with all players providing written informed consent, with the team manager providing written consent for players less than 18 years of age to participate in the present study (Appendix 1, Appendix 2). The present study was approved by the Bond University Human Research Ethics Committee (BUHREC).

Training Analysis

Training drills were recorded with a Sony digital high definition video recorder (HDR - XR260E, Sony, California, USA) with a remote control tripod (VCT- 80AV, Sony, California, USA). The varying locations of training camps meant that video footage was captured with elevation ranging from five to 15 metres above the training ground, with the camera typically placed at the halfway line of the field. The attacking team's performance was analysed during game-based drills and only periods of activity were included in the duration of each drill. The game-based drills were chosen for analysis due to the similarities to match demands, as determined by the coaching staff. The aim of the game-based drills was to focus on the technical and tactical skills of a match, so all game-based drills were conducted using the full field with seven attacking players and seven defensive players, except during no defence. Game-based drills were evenly distributed across training camps and between morning and afternoon training sessions. The description, number of occurrences, total duration and average duration of each game-based drill during training camps is demonstrated in Table 11. Manual notational analysis was performed with no specific coding software used. Windows Media Player (Microsoft, Washington, USA) was used to view video footage that was analysed in lapsed time, where the analyst was permitted to pause and

replay video footage, to enhance the accuracy of coding (119). Coding sessions were conducted over a maximum of two hours, with at least a one hour recovery between analysis sessions (119). The coding template used for the analysis of attacking variables is presented in Appendix 3.

Table 11: Description and distribution of time spent in each game-based drill for all training camps.

Game-based drills	Description	Total occurrences of drill	Total duration (min)	Average duration (min)
Fiji	Once touched or tackled return to halfway and start attacking movement again. The drill focused on passing, evasive moves and efficiency in attack.	6	45	8 ± 4
Penalties	Taking penalties from varying locations on the field. The drill aim was to work on tactics and attacking movements from different locations.	4	12	3 ± 1
Restarts	Receiving restarts. The drill focus was to work on formation and set-up for receiving restarts and the tactics and ball movement from a restart.	8	37	5 ± 2
Rucks	Rucks at varying field locations, with the coaching staff varying the speed of ball release from the ruck. The drill aimed to develop team tactics depending on the location and the speed of ball release from the ruck.	6	45	8 ± 3
Set-piece	Includes the set-up and execution of attacking scrums and line-outs. Coaching staff were developing technical elements associated with performing a scrum or line-out combined with the ball movements and tactics the team were aiming to execute.	8	52	6 ± 2

Team play	Is an integration of all skills developed throughout the other five game-based drills, including scrums, line-outs, penalties and general match play. The drill focus was to combine all skills and tactics learnt and apply it to a variety of situations as opposed to just being used in isolation. Coaches also utilised the drill to evaluate if players have an understanding of team tactics.	10	87	9 ± 4
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Data are presented as totals, except for average duration which are presented as mean ± SD.

The attacking outcome measures for the present study were based on the rugby sevens match literature, and the tactical importance of maintaining ball possession and efficiency in attack (53, 61). The attacking outcome measures included pass type, pass accuracy, catching, evasive moves and line breaks that were all analysed per player possession in relation to the three varying levels of defensive pressure. The distribution of time spent and the number of passes performed in each type of defensive pressure are shown in Table 12.

Defensive Pressure

Defensive pressure is one of the most important task constraints, due to its strong influence on an attacking team's performance and success (10, 67, 70). Defensive pressure was described as:

1. *No defence* – No opposing players in a defensive line.
2. *Uncontested defence* – Opposing players present in a defensive line, but were only allowed two handed touches on the attacking team, with no contact or contest during the ruck.
3. *Contested defence* – Opposing players in a defensive line who were allowed to make full contact including tackling and rucking.

Pass Type

Successful rugby sevens teams may need to utilise a variety of passes to be efficient in attack and make line breaks (61). Consistent with previous studies (61, 119), pass type was classified as:

1. *Conventional* – The ball is thrown backwards to another attacking player.
2. *Cut-out* – The ball goes past one or more attacking players to another attacking player.
3. *Dummy* – The ball is pretended to be thrown to a teammate, but does not leave the player in possession.
4. *Switch* – The ball goes in the opposite direction to the movement of the passing player.
5. *Offload* – The ball is passed after the ball carrier makes contact with at least one defensive player.

Pass Accuracy

Pass accuracy is an essential technical ability for rugby sevens, as it allows attacking teams to move the ball to a player in a better attacking position and attack with greater efficiency under defensive pressure (53, 54). Consistent with previous research (119), passing accuracy was defined as:

1. *Good* – The ball was received between chest and hip height. At most, minor adjustments to posture or line of motion were made by the catcher to receive the pass.
2. *Moderate* – The ball was received between chest and head height or between hip and knee height. Adjustments to posture or line of motion were made by the catcher to receive the pass.
3. *Poor* – The ball was received by reaching above head height, below knee height or the ball did not get to the player on the full. Major adjustments to posture or line of motion were made by the catcher to receive the pass.

Catching

Successful teams are able to limit errors and maintain possession of the ball better than unsuccessful teams, limiting the time their opposition are in possession and their opportunities to score (54, 112). Catching was categorised as:

1. *Successful* – The receiving player catches the ball.
2. *Unsuccessful* – The receiving player drops the ball either forward or backwards, regardless of pass quality.

Evasive Move

Successful teams are more efficient in attack and execute an evasive style of play, not only through passes but with evasive moves (52, 61). An evasive move was defined as non-linear motion where a player tries to get around or avoid an opponent (100). Consistent with previous studies (100), evasive moves include:

1. *Side-step* – Involves a sideways stepping motion to avoid an opponent.
2. *Swerve* – A forward change of direction in order to get around an opponent.

Line Break

During international rugby sevens matches, successful teams had more line breaks compared to unsuccessful teams (61). A line break was defined as when an attacking player gets through the opponent's defensive line while in possession of the ball (27). Consistent with previous studies (27, 61) line breaks were classified as:

1. *Yes* – A line break occurred.
2. *No* – A line break did not occur.

88 **Table 12:** Distribution of time spent and the number of passes performed in each type of defensive pressure.

Defensive pressure	Total occurrences during drills	Total duration (min)	Average duration (min)	Total passes performed	Average passes per min
No defence	8	44 (16%)	5 ± 3	764	17 ± 2
Uncontested defence	29	188 (67%)	6 ± 4	2398	13 ± 3
Contested defence	8	46 (17%)	6 ± 2	576	12 ± 4

Data are presented as totals (percentage of total time in game-based drills), except for averages which are presented as mean ± SD.

Reliability

Intra-tester reliability of all outcome measures was established by analysing six training camps drills, that were captured from a variety of elevations and were re-analysed a week later by the same analyst. The reliability procedures were based on established protocols that are advocated for the use in performance analysis literature (100, 119). Intra-tester reliability utilising Kappa test statistic revealed that there was a very high level of agreement (0.98, range = 0.91 to 1.00) for all variables. The mean Kappa test statistic of 0.98 was almost identical to previous performance analysis studies in rugby league and rugby union (89, 118, 119).

Statistical Analysis

Data were presented as a percentage within each of the defensive pressure categories, to account for the variation of time spent training in the three levels of defensive pressure. Chi squared (χ^2) tests were used to examine the association between the different levels of defensive pressure and the attacking skills of rugby sevens players. Data were presented as degrees of freedom, chi squared statistic and level of significance. Chi squared tests were determined by comparing an observed frequency for a particular category to an expected frequency for that category. The SR provides further insight into the subcategories that contributed to the chi square and to understand the association between defensive pressure and the probability of the different skills being observed. Standard residuals are an indication of how many deviations above or below frequencies observed in particular subcategories are to the frequencies you would expect to observe in those subcategories by chance (33). A SR ≥ 2.0 is typically used to represent an event that was more likely to happen than expected by chance, whereas a SR ≤ -2.0 represents an event that was less likely to occur than expected by chance. A SR threshold of ≥ 2.0 and ≤ -2.0 provides practically meaningful results regarding the changes in observed variables between defensive pressure conditions (33). The level of significance was set at $p < 0.05$, with SPSS (version 20, SPSS Inc. Chicago, USA) used for all statistical analyses. The current statistical approach has been commonly employed in performance analysis research (100, 117-119).

Results

Chi squared analysis revealed a significant relationship between defensive pressure and the frequency of pass type ($\chi^2(8) = 190.6$, $p < 0.001$). A cut-out pass (SR = 3.3) and dummy pass (SR = 2.3) were more likely to happen than expected by chance during uncontested defence, however a cut-out pass (SR = - 3.6) and dummy pass (SR = - 3.7) were less likely to happen than expected by chance during no defence. A cut-out pass (SR = - 2.6) was also less likely to occur than expected by chance during contested defence. A switch pass was more likely to happen than expected by chance during no defence (SR = 3.7) and less likely to happen than expected by chance during contested defence (SR = - 3.2). An offload was less likely to happen than expected by chance during uncontested defence (SR = - 2.2) and more likely to occur than expected by chance during contested defence (SR = 9.6) (Figure 2).

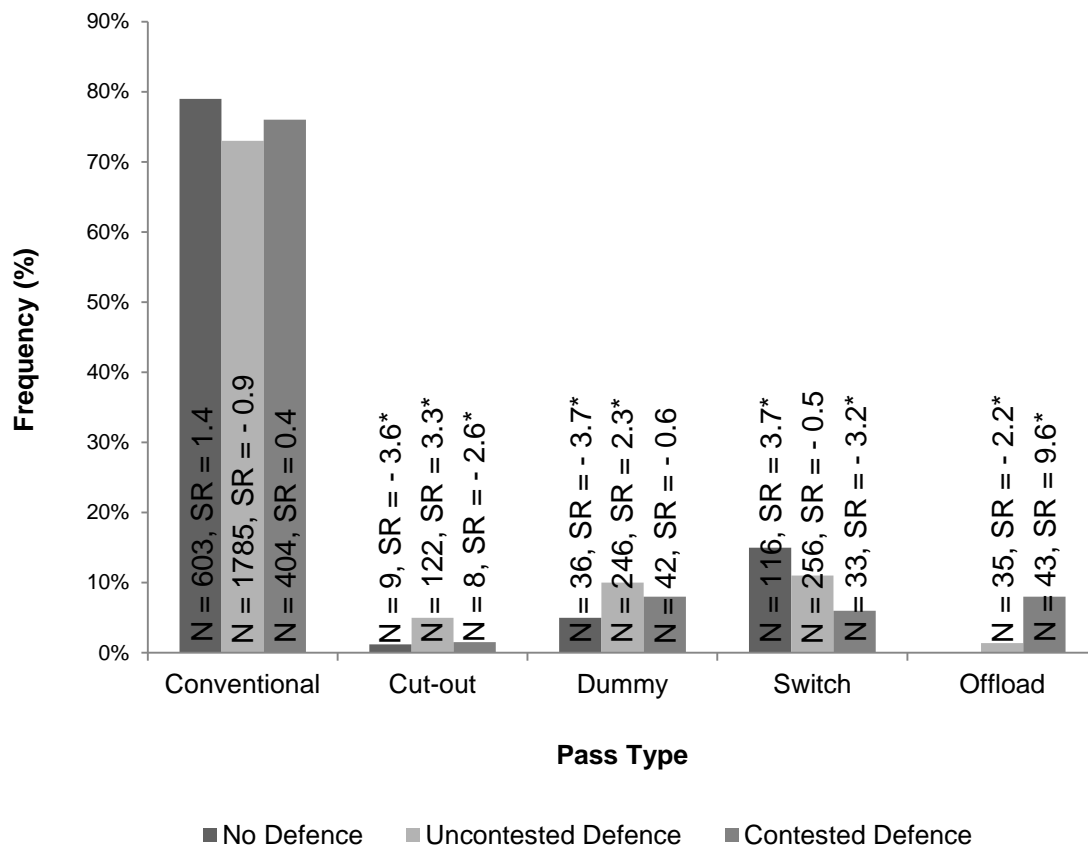


Figure 2: The relationship between defensive pressure and the frequency of conventional, cut-out, dummy, switch and offload passes. * Significant association (SR ≥ 2.0 or SR ≤ - 2.0).

Defensive pressure had no significant effect on the frequency of accurate passes ($\chi^2(4) = 13.2, p = 0.067$). No defence had the most accurate passing with 60% good accuracy compared to 55% during contested defence. No SR achieved significance, with the closest being a good pass which was more likely to occur than expected by chance during no defence (SR = 1.9) (Figure 3).

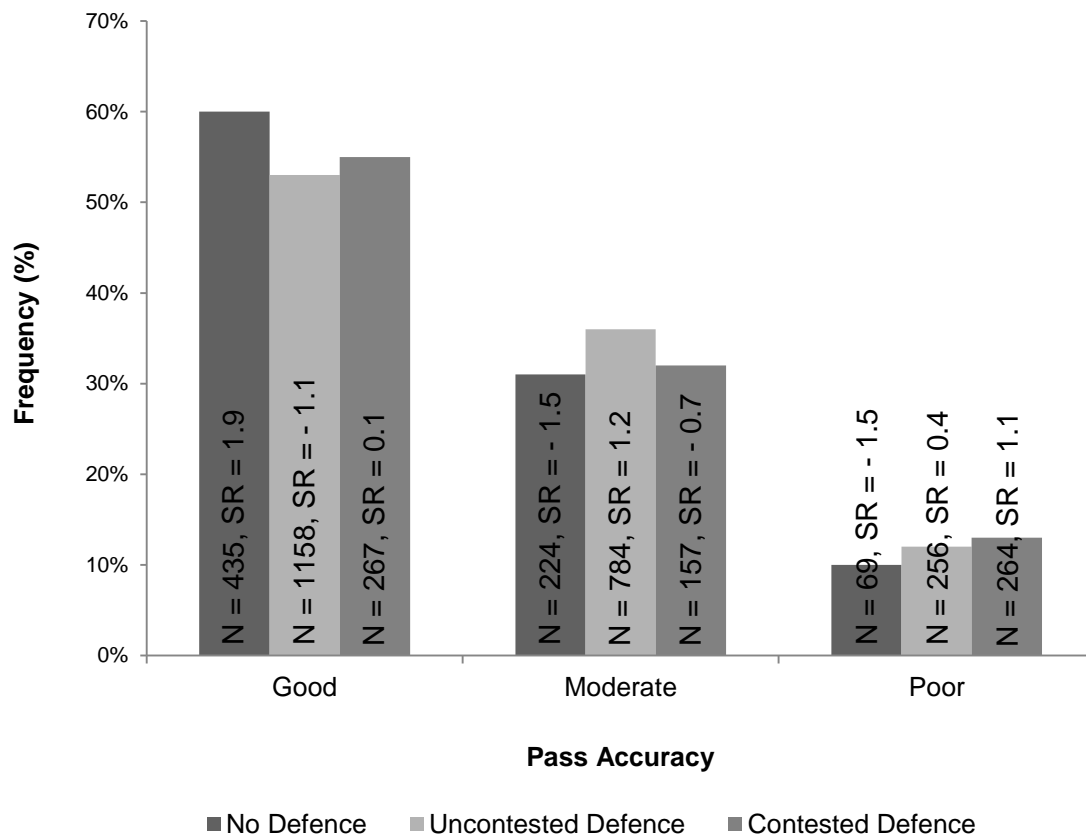


Figure 3: The relationship between defensive pressure and the frequency of good, moderate and poor passes. * Significant association ($SR \geq 2.0$ or $SR \leq -2.0$).

The percentage of successful catches was greater than 95% for all levels of defensive pressure (Figure 4). There was no significant relationship between defensive pressure and the frequency of successful and unsuccessful catches ($\chi^2(2) = 2.6$, $p = 0.279$). All SR were non-significant, ranging from -1.4 to 0.5. Defensive pressure had a significant effect on the frequency of evasive moves performed ($\chi^2(2) = 11.2$, $p = 0.004$) and the frequency of line breaks ($\chi^2(2) = 69.9$, $p < 0.001$). A swerve (SR = 2.5) was more likely to occur than expected by chance during contested defence. During contested defence, 9% of all ball carries resulted in a line break which was more likely to happen than expected by chance (SR = 4.7).

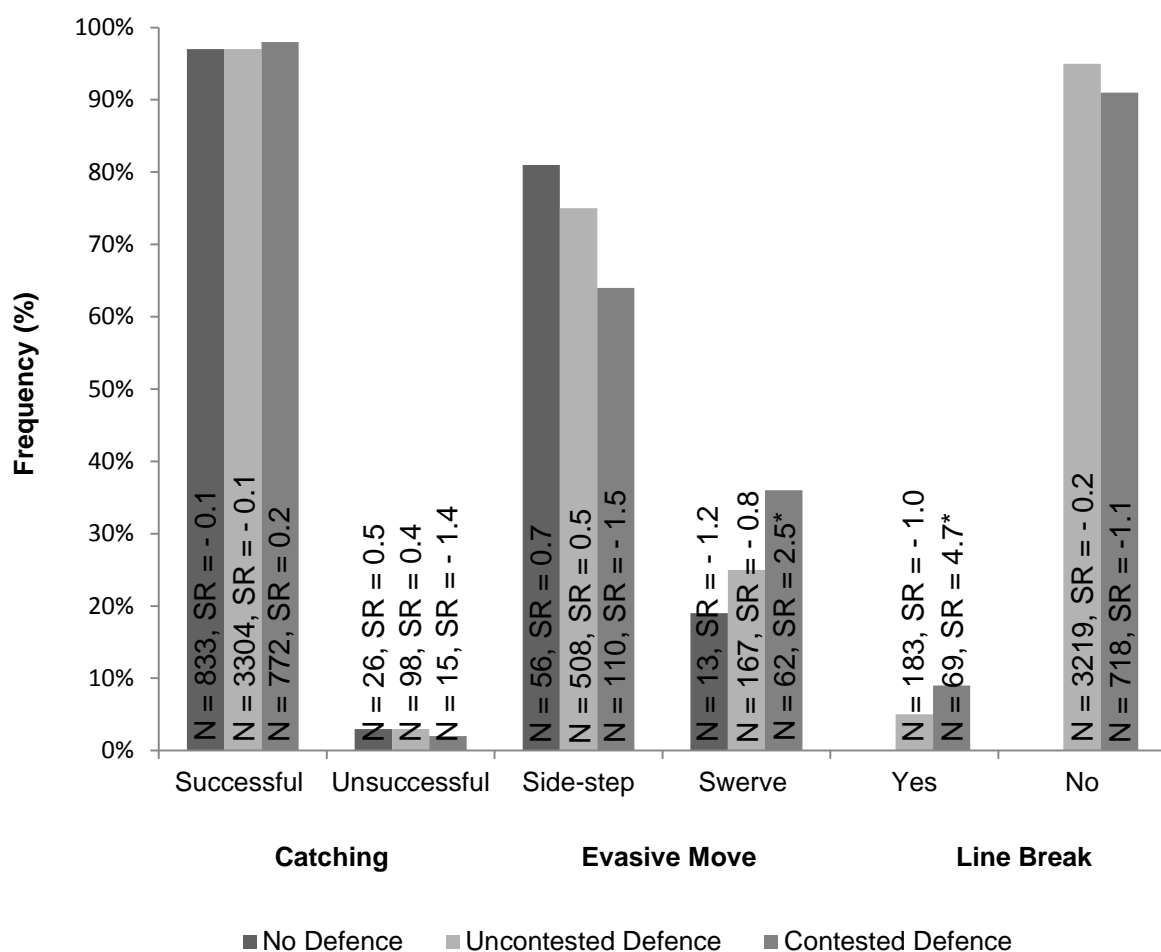


Figure 4: The relationship between defensive pressure and the frequency of successful and unsuccessful catches, evasive moves and line breaks. * Significant association ($SR \geq 2.0$ or $SR \leq -2.0$).

Discussion

The present study provides insight into the technical skills of rugby sevens training camps sessions in relation to varying levels of defensive pressure. By gaining an insight into how varying the constraints of defensive pressure affected skill frequency, coaches may be able to improve the periodisation and progression of technical and tactical training drills. Effective periodisation and progression of training drills will improve skill acquisition and better prepare players for rugby sevens matches and tournaments.

Passing is an essential skill in rugby sevens, with the present study demonstrating that there was a significant relationship between defensive pressure and the frequency of pass type. A conventional pass was the most common type of pass performed during all three levels of defensive pressure. Non-conventional passes including a switch pass and a cut-out pass were more likely to occur than expected by chance during no defence and uncontested defence, respectively. In comparison to the results that a switch pass and a cut-out pass were more likely to be performed during no defence and uncontested defence, a cut-out pass and a switch pass were less likely to occur than expected by chance during contested defence. The reduction in the frequency of non-conventional passes during contested defence was not expected, as it was hypothesised that the players would perform more of the non-conventional passes to attack with greater efficiency (as defined by a smaller number of passes per try) to overcome the increased defensive pressure. The present study's hypothesis was based on research demonstrating higher ranked teams in international men's rugby sevens tournaments had greater attacking efficiency (61) and an increased ability to maintain possession of the ball, with more passes per try being associated with worse team rankings (54). Efficiency in attack also differentiated quarter-finalists and semi-finalists, with semi-finalists having more possession and converting it more efficiently into points (109). A number of reasons may explain the reductions in non-conventional passes with contested defensive pressure. The first reason is the greater physical demands of impacts, rucks and tackles performed during contested defensive pressure, may have contributed to increased physical and cognitive fatigue. It is also possible that the increased defensive pressure reduced the time the attacking players had to make decisions regarding, when and how to perform key skills such as running, passing and catching. Coaches, therefore need to be aware of the physical, technical and tactical demands and the interaction that occurs.

With the exception of offloads (which occurred more frequently during contested defence), results of the present study suggest that during contested defence, players were less likely

to utilise non-conventional passes, such as cut-out, dummy or switch passes. The constraints-led approach would suggest that the coaches may need to alter the task constraints, instructions, cues and or feedback given during contested defence, game-based drills. Such alterations to task constraints or the communication approach utilised by the coaches, must encourage the performance of non-conventional passing skills that are more likely to result in line breaks. The more frequent practice of these non-conventional passes during contested defence, will better prepare the players to execute these passes in contested defensive situations inherent to competition (93).

While the type of pass is essential to the tactics employed, the importance of accurate passing during rugby sevens matches should not be underestimated with 53% of tries scored with three or less passes and only 12% of tries scored with five or more passes, during four IRB Sevens World Series (52). With a limited opportunity of 3 or less passes to score a try, passes need to be accurate in order to be efficient in attack. The present study found that there was no significant relationship between defensive pressure and pass accuracy, with good passes only exhibiting a 5% non-significant decrease and poor passes a 3% non-significant increase from no defence compared to contested defence. The present study reported a substantially smaller decline in passing accuracy than that observed by Orth et al. (82), who found passing accuracy during soccer drills decreased from 78% for a defender absent to 59% for a defender near. While the decline in passing performance was better during the present study, rugby sevens players may have been able to maintain passing accuracy by performing fewer non-conventional passes. By encouraging the performance of non-conventional passes and continually striving to improve decision making and passing accuracy, players will increase exposure to the relevant perceptual information of match-like situations, that should assist players to develop the appropriate perceptual-action coupling and transfer skills from training to match performance (32, 93).

The present study found that there was no significant effect of defensive pressure on the catching ability of rugby sevens players. Women's rugby sevens players caught the ball greater than 95% of the time, regardless of the level of defensive pressure or pass accuracy. Hughes et al. (61) also reported no significant difference for handling errors between successful and less successful teams during men's rugby sevens matches. While a poor pass was still likely to be caught by the players in the present study, it may have required the catching player to change direction, speed and or devote a greater degree of attention to the task of catching the pass. The changes in direction, speed and or greater degree of attention to catching a poor pass, may increase the reaction and movement times required to catch the ball and then perform a pass and or evasive movement, reducing the efficiency in attack

(44, 84). Maintaining possession is linked to both the passing and catching ability of rugby sevens players and has been shown to be a key determinant for successful teams in rugby sevens tournaments (109). The present study's results and that of the literature (52, 53) may suggest that while catching is important, rugby sevens players and coaches may need to focus more of training on improving the frequency of non-conventional passes during contested defensive pressure. The contested defence experienced during game-based drills of the present study, however may not be as intense as what is experienced during competition, due to a number of factors that cannot be replicated at training including the opposition, the pressure to win matches, the crowd influence, anxiety and adrenaline associated with competition.

Defensive pressure has been demonstrated to have a significant effect on the frequency of line breaks and evasive moves, with line breaks and swerves more likely to happen during contested than uncontested defence. During no defence, a line break could not occur so comparisons were between uncontested and contested defence. Results of the present study indicated that contested defence had the highest number of line breaks with 9% of all ball carries resulting in a line break which was more likely to occur than expected by chance. A higher number of evasive moves such as a side-step and swerve were associated with successful teams compared to less successful teams during men's rugby sevens matches (61). With the potential for players to be more closely aligned and compressed during contested defence, more space is created away from the ruck at the end of the defensive line, encouraging players to perform a swerve in order to create line breaks. During contested defence players may be more compressed because of the increased demands to tackle as opposed to uncontested defence which only involved a two hand touch. Two hand touch required for uncontested defence may allow the defence to cover a greater area by not requiring additional players to commit to the breakdown or support the tackler in case of a missed tackle. With only seven players on the field, committing two players to a tackle or ruck situation during contested defence creates space in the defensive line that the attacking team need to be able to utilise effectively. Contested defence, therefore provides opportunities for rugby sevens players to develop the essential skills required for evasive moves and line break situations.

Defensive pressure was demonstrated to affect the frequency and execution of attacking skills including pass type, evasive moves and line breaks in international women's rugby sevens players. Coaches need to be aware that their instructions either before or during the drills, along with the rule constraints they impose on the specific game-based drills, have the potential to alter players tactics and execution of particular skills. For example, if the coach

gets the players to focus on minimising errors and maintaining possession as opposed to being efficient in attack, it is likely the players will revert to less complex tactics and conventional passing options. Different weather conditions (temperature, precipitation, wind) and ground conditions experienced from the various locations may have also impacted on the tactics employed during specific training sessions or camps (48, 83). The influence of coaches instructions and rule constraints along with environmental conditions were not able to be controlled due to the observational nature of the present study. However, rugby sevens is an outdoor sport played in a variety of locations around the world, variability of conditions is a factor players need to be able to handle during competition.

Conclusion

In conclusion, the present study demonstrated that defensive pressure significantly altered the frequency of skills including pass type, evasive moves and line breaks. The more frequent execution of conventional passes during contested defence suggest that the coaches might need to alter the task constraints, instructions, cues and or feedback given during contested defence, game-based drills. Such alterations to the task constraints, instructions and or feedback must encourage the performance of non-conventional passes, so that the players are better able to execute these passes in contested defensive situations inherent to competition (93). By encouraging the performance of non-conventional passes and continuing to improve passing accuracy during contested defensive pressure, players will be increasingly exposed to the relevant perceptual information that should assist in the development of the appropriate perceptual-action coupling and transfer of skills from training to match performance (32, 93). Contested defence also was shown to provide opportunities for rugby sevens players to develop the essential skills required for evasive moves and line break situations likely to be encountered in game situations where the defence may be more compressed due to the requirements to perform tackles and compete at the breakdown. As high levels of skill execution are highly related to the likelihood of winning matches and tournaments during rugby sevens (53, 54), coaches may need to structure the technical and tactical demands of the overall training program. These annual training programs may need to involve some individuality for players with different technical and tactical skills so to progressively overload the technical and tactical training demands in order for the technical and decision making skills to develop and transfer to match performance. As increased physical demands may affect the frequency and execution of key attacking skills performed by the players, coaches may also need to monitor the physical, technical and tactical demands of training sessions to obtain the desired training outcome

Chapter Five: Discussion

The sport of rugby sevens has evolved over the past 20 years culminating in rugby sevens being recognised as an Olympic sport at the 2016 Olympic Games in Rio de Janeiro, Brazil. While considerable research has been conducted on the physical, technical and tactical demands of rugby union matches (5, 106, 119) and the effect of a variety of training approaches (3, 12, 20), much less is known about rugby sevens. Rugby sevens is played at a much higher relative running intensity compared to rugby union (55, 104), and the greater space available for rugby sevens compared to rugby union players is likely to create different technical and tactical demands (54). The likely physical, technical and tactical differences between rugby sevens and rugby union suggests that additional research needs to be conducted into rugby sevens as comparisons to rugby union are somewhat limited.

A review of the literature was conducted to develop an understanding of the existing literature surrounding rugby sevens. The peer reviewed research on rugby sevens is expanding with men's and women's matches quantified through several studies (55, 88, 104). Limited studies have examined training practices of rugby sevens players (24, 31, 57) despite training improving and preparing players for tournaments (24). The results of the literature review suggest that gaps still exist within the rugby sevens literature and further research is needed, the biggest gap concerns our understanding of current training practices and their likely effectiveness in improving tournament performance. The two studies included in the present thesis were observational in nature, in order to describe key aspects of current training practices used by coaching staff in international women's rugby sevens preparation training camps. Training camps are important to the preparation of rugby sevens teams due to the challenges surrounding the decentralised rugby sevens programs of qualifying teams for the World Rugby Women's Sevens Series, state teams involved in national championships and the introduction of new players for tournaments to centralised programs. The primary focus of the training camps examined in the present thesis was to improve the technical and decision making skills in context with game specific tactics. Monitoring of physical, technical and tactical demands during training sessions is important for rugby sevens players because of the limited days to prepare a team for competition during training camps. Due to the limited days to prepare a team for competition, coaches need to manage the complex interaction between the physical, technical and tactical demands of training drills, sessions and camps. The two studies of the present thesis were conducted to:

1. Quantify the movement patterns of preparation training camps for international women's rugby sevens players.
2. Determine the effects of the level of defensive pressure on the frequency and execution of key attacking skills for international women's rugby sevens players during training camps.

Movement Patterns of Training Camps

Study one, as presented in chapter three of the thesis, sought to quantify the movement patterns of preparation training camps for international women's rugby sevens players. Despite the importance of preparation training camps leading into tournaments, no studies have yet investigated rugby sevens training camps. Twenty four international women's rugby sevens players participated in the present study with GPS and sRPE data collected from 28 on-field training sessions over seven training camps. Key outcomes assessed were for the absolute and relative movement patterns that included training load, total distance covered, distances covered in high velocity zones, the number of accelerations, decelerations, sprints, and repeated sprints. All training sessions were analysed and included the entire duration of the session, even where periods of inactivity occurred for coaches to provide feedback or for the players to recover in between drills.

The findings of study one demonstrated that women's rugby sevens players covered a total median (IQR) distance of 3823 (3126 – 4398) m and a relative distance of 2655 (2267 – 3030) m/hour during preparation training camps with a duration of 91 (76 – 98) minutes. Training camp sessions were substantially longer than the duration of rugby sevens matches, that resulted in training sessions that were less intense than matches in terms of the absolute and relative movement patterns. Based on the comparisons to rugby sevens matches, when considering training camp sessions as a whole, the physical demands have been insufficient to enhance or maintain physiological adaptations. The differences observed between training sessions of the present training camps and rugby sevens matches were to be expected due to the focus of training camps to develop technical and tactical skills. The focus on technical and tactical skills meant that the coaching staff needed to reduce the intensity of training from what would be found in competition, to improve team cohesion along with players technical and tactical skills. As a result of the focus of training camps, the coaches also provided regular feedback to their players. The intermittent breaks that occurred within training sessions where coaches provided feedback, instructions and

explanations or when the players' had drinks breaks would have reduced the relative movement patterns.

Coaches need to be aware that if training camps are focusing on the technical and tactical skills, that the physical demands still need to be maintained if detraining of the players physical conditioning is to be prevented. While detraining is unlikely to occur over the two to four days of one training camp, negative physiological effects may be more evident over the four months in which the present training camps occurred. It is essential that the regular monitoring of movement patterns during training camps occurs, to ensure that training sessions and camps not only address the technical and tactical skills but also the physical demands required for competition. In order to address specificity of training and to promote physiological adaptations, some of the training session needs to include components that replicate the physical demands of matches by reducing the duration and increasing the intensity of training. To ensure that these portions of the training sessions are more intense and the duration is reduced, coaches need to consider the impact that disruptions or breaks in activity may have on the physical demands and organise training sessions to minimise disruptions in activity.

The absolute and relative high-intensity efforts including accelerations, sprints and repeated sprints appeared to be periodised throughout the four sessions of a training camp. Accelerations, sprints and repeated sprints have been shown to be more energetically demanding than running at a constant velocity and impose greater internal load on players (85, 110). The periodisation model used by the coaches appeared to involve increasing training load from session 2 to 3 and a reduction in training load from session 3 to 4. The changes in training load were evident by increased frequency of high-intensity efforts including accelerations, sprints and repeated sprints from session 2 to 3 and a reduction in these variables from session 3 to 4. In contrast, no significant differences were observed between the training sessions in terms of the distances covered at HIR or sprinting velocity zones. The lack of any significant difference for the distances covered at HIR or sprinting velocity zones, may mean that the different training sessions performed across each training camp involved drills that required relatively consistent amounts of HIR and sprinting. The regular monitoring of training camp movement patterns will assist coaching staff to better quantify and implement periodisation of the physical demands within training camps and to ensure that training sessions within camps address not only the technical and tactical skills but also the physical demands required for competition.

Perhaps the biggest challenge for sport scientists who wish to use GPS to monitor the physical demands with high performance teams, is the vast number of variables that can be obtained from GPS units. The absolute and relative movement patterns assessed in the present study included training load, total distance covered, distances covered in high velocity zones, the number of accelerations, decelerations, sprints and repeated sprints. While the GPS measures in the present thesis included a number of movement patterns, additional measures could have provided a more complete understanding of the training demands. Additional measures that could have been used include average and maximal HR, the time spent in each HR zone, as well as work to rest ratios and the number and magnitude of impacts and collisions. All GPS, accelerometer and HR measures provide a potentially greater understanding of training demands, however it may be unrealistic to monitor and track all measures provided from GPS, accelerometer and HR data in a team environment. In order to be practical and applicable to rugby sevens teams and the realistic time spent analysing data, the measures deemed most appropriate based on the rugby sevens literature and in conjunction with the coaching staff were analysed for training sessions.

Technical Skills of Training Camps

Match play in many team sports provides significant defensive pressure that is not always replicated in training drills, that could suggest why defensive pressure has been shown to affect technical skill execution during training (70, 82). The purpose of study two, as presented in chapter four, was to determine the effects of the level of defensive pressure that included no defence, uncontested defence and contested defence, on the frequency and execution of key attacking skills of international women's rugby sevens players during training camps. To determine the effects of defensive pressure, performance analysis was conducted on 42 preparation training camp drills, over seven training camps during the 2012 – 2013 international women's rugby sevens season. Training drills were recorded using a video camera and the attacking team's performance was assessed during game-based drills, where the focus was on performing the technical and tactical skills of a match. Manual notational analysis was performed in lapsed time, with video software use to view the footage. The attacking outcome measures included pass type, pass accuracy, catching, evasive moves and line breaks.

The findings of study two demonstrated that defensive pressure significantly affected the frequency of skills including pass type, evasive moves and line breaks. Non-conventional

passes such as a cut-out, dummy or switch pass were executed less frequently during contested defence. The reduced frequency of non-conventional passes during contested defence was not expected based on previous research where successful teams attacked with greater efficiency, through a smaller number of passes and possession time per try (54, 61). Non-conventional passes performed less frequently may reflect the greater physical demands of impacts, rucks and tackles performed during contested defensive pressure. The greater physical demands of contested defence may have contributed to increased fatigue as well as reduced the decision making time, ultimately leading to the attacking players reverting to the more frequent use of conventional passes.

Although pass type was significantly affected by the level of defensive pressure, the passing accuracy and catching ability of international rugby sevens players was not significantly affected. The present results suggest that international players perform accurate passes and catch most passes regardless of the level of defensive pressure. However, by increasing the complexity of catching the ball from a poor pass, the catching player may need to change direction, speed or devote a greater degree of attention to the task. Changes in direction, speed or degree of attention required may increase the reaction and movement times required to complete the next movement and reduce the attacking efficiency (84). If the coaches were to encourage the performance of non-conventional passes while trying to maintain passing accuracy during contested defensive pressure, players would be increasingly exposed to the relevant perceptual information, that should assist in the development of the appropriate perceptual-action coupling and transfer of skills from training to match performance (32, 93).

Contested defensive pressure during game-based drills provided players with greater opportunities to perform swerves and line breaks, as the defence may be more closely aligned and compressed. As swerves and line breaks are related to success in rugby sevens tournaments (61), the present results further highlight the importance of the coaches instructions to their players and in having progression of defensive pressure to develop all the skills required for successful performances during competition. While the findings of study two demonstrated that the frequency of skills including pass type, evasive moves and line breaks were significantly affected by defensive pressure, a number of additional factors could have potentially impacted on the results of the present study. The changes in technical skill execution, particularly non-conventional passes with contested defensive pressure may have been a reflection of the coaches' instructions such as minimising errors and maintaining possession as opposed to attacking with efficiency. The different drills that were included in game-based drills had slightly different rule constraints. While all game-based

drills were similar and had the same overall goal of developing skills of match play as a team, the minor changes in rule constraints, could potentially have affected the comparisons between different levels of defensive pressure (48, 83). Depending on the intensity and duration of prior exercise before game-based drills, players may have already experienced acute fatigue, with the potential for contested defence to further contribute to fatigue and negatively impact technical and tactics skills performed during game-based drills. The longitudinal observational study design and different locations of training camps meant that different weather conditions (temperature, precipitation, wind) and ground conditions were likely to have existed between training camps. While the weather and ground conditions could have impacted on the tactics employed during specific training sessions or camps, seven training camps were collected in an effort to account for any potential that varying weather conditions may have had on the results obtained (48, 83).

Regardless of the uncontrollable factors that may have influenced aspects of the findings during the present study, these results still have much practical significance to the sport of rugby sevens. Coaches may want to progressively overload the technical and tactical skills, to develop optimal decision making and skill execution that will transfer to match performance. In order for the skills and tactics developed during training sessions to transfer to competition, players need to be able to perform non-conventional passes under contested defensive pressure (32). In addition to the progression of defensive pressure during training to ensure a transfer to match performance, the monitoring of technical and tactical demands in conjunction with the physical demands is needed to quantify the interaction between these demands and the desired outcomes.

Conclusion

Specificity of training is important for preparing players for competition and to maximise match performance. Specificity of training applies to the physical, technical and tactical demands of match play, whereby training needs to replicate all of these demands. Due to the limited days to prepare a team during rugby sevens training camps, the physical, technical and tactical demands need to be achieved somewhat simultaneously. The interaction between the physical, technical and tactical demands of training sessions needs to be taken into account to provide balance when trying to develop certain aspects within particular drills or sessions. As a result of the strong focus on the technical and tactical skills and developing team cohesion, the training sessions when considered as a whole may be insufficient to enhance or maintain physiological adaptations. Differences between training

sessions of the present training camps and rugby sevens matches was to be expected, as the intensity of the movement patterns performed and the level of defensive pressure encountered during competition is unlikely to ever be fully replicated during training. Training camp sessions were, however substantially longer than the duration of rugby sevens matches, that resulted in training sessions that were not as intense as matches. The development of new technical and tactical skills and the emphasis on developing team cohesion throughout training camps may be a potential reason why coaches reduced the intensity of training sessions compared to what was encountered during competition. Reductions in training intensity would better allow players to improve technical and decision making skills in context with game specific tactics, however the strong emphasis on technical and tactical skills resulted in the conflicting demands between movement patterns and technical and tactical development. The absolute and relative high-intensity efforts including accelerations, sprints and repeated sprints appear to be systematically varied throughout sessions of training camps, as they are more energetically demanding than running at a constant velocity and impose greater internal load on players (85, 110). The reduction in movement patterns over training camps supports the use of periodisation by the coaching staff throughout the training camps. The periodisation of movement patterns would allow for players to improve technical and tactical skills, however the importance of sufficient physical stimulus should not be overlooked by coaching staff preparing a team for competition.

Once the new skills and tactics are understood by the players, the physical, technical and tactical demands can then be progressed until the skills are performed under conditions more similar to matches with contested defensive pressure. The progression of defensive pressure may allow for the physical demands to be developed or maintained together with the technical and tactical demands, with some of the shorter duration training drills being of a similar intensity to competition. It is evident from the game-based drills in rugby sevens training camps that non-conventional passes, such as a cut-out or switch pass, were performed less frequently during contested defensive pressure, suggesting that progressing too quickly to contested defence or not providing sufficient exposure to this level of defensive pressure can lead to acute decrements in skill frequency and execution. The decrements in skill frequency and execution may interfere with the skill acquisition process and ultimately reduce performance at tournaments, as greater efficiency and the ability to accurately execute non-conventional passes may increase the probability of winning matches and tournaments (54, 61). Not only is the technical performance affected by insufficient exposure to contested defence, but without contested defence and physical demands similar to competition, the physical stimulus may also be insufficient. The present studies preparation training camps occurred over four months with the potential for players' physical conditioning

to be negatively affected and detraining to occur. Due to the limited time for a team to prepare during training camps, coaches need players performing skills under match-like conditions as this exposes the players to more realistic physical, technical and tactics demands, thereby increasing the chance for a positive transfer from training to match performance. Exposure to the appropriate perceptual information during game-based drills is likely to result in the desired execution and frequency of the technical and decision making skills that occur in the continually changing environment of matches. The physical demands of defensive pressure and the movement patterns need to be periodised over training camps to allow players to develop the required technical and tactical skills, while providing sufficient exposure to match-like conditions for a transfer of skills from training to match performance.

Coaches may need to structure training sessions to progressively overload the physical, technical and tactical demands, in order for players to be physically ready to compete and for their decision making and technical skills to develop and transfer to match performance. Alterations to the task constraints, instructions, cues and or feedback given during the contested defence, game-based drills need to encourage the performance of non-conventional passing skills such as a cut-out, dummy or switch pass, so that the players are better able to execute these passes in contested defence situations. Coaches need to be aware that the constraints, that can potentially affect skill execution such as the focus of attention on the coaches' instructions, task constraints and environmental conditions can also impact upon the physical demands through alterations in team tactics and playing style. In addition to the impact on physical demands of alterations to skill frequency and tactics, coaches need to consider the timing of breaks during training and its impact on the physical demands. When learning new skills and tactics, feedback from the coaches is an important part of the learning process. However, in order to manage the interaction between the physical, technical and tactical demands, coaches need to consider when instructions and feedback are given, in terms of not disrupting the physical conditioning that players are also getting from a training session. Monitoring of the physical, technical and tactical demands will therefore allow for a greater understanding and control of the possible interaction between the movement patterns, technical and tactical skills that may occur across various levels of defensive pressure. The present thesis has highlighted the importance of quantifying current training practices as the first step in preparing players for the movement patterns and technical and tactical skills of match play, in order for a transfer of the benefits gained during training to be evident in match performance.

Practical Applications

Rugby sevens studies identified in the literature review demonstrated the physical demands and to a limited degree the technical and tactical demands of rugby sevens matches. The literature review demonstrated that most research into rugby sevens has examined the physical demands, technical and tactical skills and attributes required to be a successful rugby sevens player. Data reported in the present thesis quantified key aspects of the movement patterns and technical skills of training camps that may be important for improving the players' physical, technical and tactical attributes and skills. The major applications of the present thesis included:

- The importance of monitoring the movement patterns of training sessions within preparation training camps, especially for semi-professional state teams in the national championships and qualifying teams in the Women's Sevens Series. Quantifying movement patterns would allow the coaching staff to alter training sessions to avoid providing insufficient stimulus or overtraining players. The frequent monitoring of movement patterns would also make it easier to manipulate aspects of training sessions in order to alter the subsequent physical demands placed on players.
- Using GPS and RPE during training sessions can be useful tools to determine if training sessions or particular drills are replicating the desired movement patterns and physical demands. The objective GPS and subjective RPE measures of the training sessions during training camps are important, as it has been demonstrated that coaches and players perceptions of a training session may differ (11, 34).
- An entire training session cannot replicate the movement patterns and physical demands of rugby sevens matches. This may be offset in several ways, coaches may deliberately utilise shorter training sessions which are conducted at a greater intensity. Coaches may also become more mindful of the impact of disruptions and breaks in activity on the physical demands, meaning they are better able to structure a training session so that different drills can develop the physical, technical and tactical demands required for competition.
- Defensive pressure does have the potential to significantly affect the frequency of rugby sevens attacking skills, especially non-conventional passes that may be required to attack with greater efficiency and increase the probability of winning

matches and tournaments (54, 61). Defensive pressure needs to be periodised over training camps to allow players to develop the required technical and tactical skills, while providing sufficient exposure to match-like conditions for a transfer of skills between training and match performance.

- Monitoring technical skill execution with defensive pressure through notational analysis provides an objective measure of the frequencies and execution of key technical skills. With coaches informed of the effects of key task constraints such as defensive pressure on the frequencies and execution of key technical skills, alterations can be made to the task constraints to better encourage the desired tactics for success. Monitoring the effects of defensive pressure on technical skills is important as the transfer to match performance is likely to be maximised when training is performed under contested defence.
- Notational analysis of the technical skill execution, that is rarely conducted during training, provides relevant data on the team and individuals technical abilities, as well as an understanding of team tactics. Notational analysis can quantify skill frequencies of specific training drills and be used in the same way as GPS to monitor players across sessions and within sessions.

Coaching and strength and conditioning staff may be able to use the findings from the present thesis to improve current training practices. By having a greater understanding of the movement patterns and technical skills of preparation training camps, coaches will be better able to understand the importance of periodising not only the physical demands of the movement patterns but the defensive pressure and technical skills as well.

Limitations

While conducting the research for the present thesis, it was apparent that there were some limitations, that potentially impacted on the results obtained and the generalisability of the data.

Movement Patterns Study

- The observational nature of the present study design meant that I had no control over the training camps, with the coaching staff selecting the players who attended the

training camps and who wore the GPS units. As a result, the players in attendance varied over the course of data collection as did the players being monitored.

- The validity of a 5 Hz GPS units for determining the distance covered at HIR and sprinting has been shown to underestimate distance by 12% and 19% respectively over 20 m (62). The questionable validity of 5 Hz GPS units used in the present study to characterise and differentiate rugby sevens players HIR and sprinting distances may, therefore negatively influence the potential applicability and generalisability of the present high velocity running data to rugby sevens players.
- The data collected in the present study were obtained from one team. As many teams generally adopt a relatively consistent style of play, observations of different teams with a different style of play or approach to training and preparation may observe different results to what was reported in the present study. Coaches with different training philosophies and players with different skill level and attributes may yield different results from those in the present thesis also.

Technical Skills Study

- The observational nature of the technical skills study, meant I again had no control over the players who participated in the game-based drills, the duration and number of occurrences of these drills and the placement within the training sessions and training camps. The lack of control over training camps, therefore resulted in some variation within and between the different game-based drills in relation to the duration and occurrences within the training sessions and training camps.
- Intra-tester reliability had very high levels of agreement (0.98) for all variables, however no inter-tester reliability was established for the variables assessed during the present study. During analysis of the data, performance analysis was completed very consistently, however a different analyst may potentially report somewhat different results, based on their interpretation of the operational definitions provided.
- Changes in the frequency of technical and tactical skills with varying levels of defensive pressure may be influenced by additional internal and external constraints on the players performance. Coaches instructions may alter players perceptions to focus on minimising errors and maintaining possession as opposed to attacking with efficiency. The minor changes in rule constraints of the game-based drills could have potentially affected the results observed. Prior exercise before game-based drills may

have caused acute fatigue, with the potential for contested defence to further contribute to fatigue and negatively impact technical and tactics skills performed. The different weather conditions (temperature, precipitation, wind) and ground conditions that occurred over the training camps could have also impacted on the tactics employed during specific training sessions or camps.

Directions for Future Research

The present thesis has made an original contribution to our knowledge and understanding of the preparation of rugby sevens players during training camps. Data from the present thesis provides a greater understanding of the movement patterns and technical and tactical skills currently employed and how the interaction between the physical, technical and tactical demands need to be controlled and periodised. Future research may investigate some of the following areas:

- With limited research into rugby sevens training, an investigation to determine what players are doing away from the training camps would be of interest in order to better understand player preparation. The effect of training individually or in small groups should also be investigated to determine the effect that current training practices have on players' physical, technical and tactical development.
- Investigate the effects of defensive pressure on the physical demands of drills used within rugby sevens training camps. Determining how movement patterns and physical demands change with varying levels of defensive pressure would provide useful data on the interaction between the physical, technical and tactical demands of rugby sevens training.
- Monitoring the physical demands of training camps compared to regular training over a short and longer term period, may allow coaching staff to determine the appropriate training loads required to ensure physical adaptations and to maximise performance at upcoming tournaments. Monitoring of training over short and longer term periods may also demonstrate how changes or fluctuations in the physical demands including movement patterns and training load may contribute or relate to injury and illness.
- The monitoring of technical skill performance to determine the time-course changes of technical skill development and how various training approaches impact on this

development for rugby sevens teams. Tournament success could also be monitored over the same time period and used to determine if improvements in training technical performance correlate to match and tournament performances.

- Notational analysis research into the key technical skills of matches for both men's and women's rugby sevens players. Research could examine the underlying factors that have been associated with successful team performance; an example could include the pass type, evasive moves and line formation that contribute to greater attacking efficiency.
- Further research could investigate the development of skill tests specific to the demands of rugby sevens matches. The development of such a test or tests could not only be used as a talent identification tool but also used to assess player's long term development or determine the effectiveness of training programs.

Research examining the physical demands of rugby sevens matches is continuing to be published, however limited research is being conducted on training demands for rugby sevens players. The results of the present thesis address this imbalance in some way by quantifying the movement patterns of training camps and the effect of defensive pressure on the frequency and execution of key attacking skills. The addition of research from the present thesis to the rugby sevens research literature and the suggested areas for future research have the potential to improve current rugby sevens training practices and match performance.

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Appendices

Appendix 1: Participant Information

EXPLANATORY STATEMENT

BUHREC Protocol Number: RO1675

STUDY TITLE: Performance analysis of the movement patterns and technical demands of international women's rugby sevens preparation training camps.

PRINCIPAL INVESTIGATORS:

A/Prof Justin Keogh (PhD)

Bond University

(07) 5595 4487

Jesse Griffin

Bond University

0431 766 309

Dr Chris McLellan (PhD)

Bond University

(07) 5595 4186



FACULTY OF HEALTH
SCIENCES AND MEDICINE

Bond University
Gold Coast, Queensland 4229
Australia

Toll free 1800 753 855
(within Australia)

Ph: +61 7 5595 4400
Fax: +61 7 5595 4122
(from overseas)

Email: hsm@bond.edu.au

ABN 88 010 694 121
CRICOS CODE 00017B

Who is doing this study?

I, Jesse Griffin a student from Bond University will be conducting two studies to help understand the movement patterns and technical demands of rugby sevens preparation training camps. The results will be used by the coaching staff of the ARU to improve or develop new training protocols to optimally prepare for tournaments.

Why are we doing this study?

I will be conducting the two studies as there is limited research surrounding rugby sevens and in particular women's rugby sevens. With the inclusion of rugby sevens in the 2016 Olympic Games, increased knowledge about the movement patterns and technical demands of training camps will assist in understanding current practises in order to enhance training.

How can you participate?

As a participant in the present studies you need to be an invited attendee at any of the Australian rugby sevens team training camps. It is also essential that support staff are informed if you are injured in anyway, as not to risk further injury.

I will not be asking you to do anything more than what is normally required of you at rugby sevens training camps. You will be asked to wear a GPS unit before training commences and throughout the training sessions. After each training session you will be asked to record a rating of perceived exertion (RPE), as determined by how hard you perceived training to be. Data are recorded and monitored throughout the training camps. In addition video footage will be recorded from training sessions, that is for technical analysis of attacking performance throughout game-based drills. All the collected data are combined to provide an overall understanding of the movement patterns and technical demands of preparation training camps throughout an international season.

Risks that you might experience

There is some potential for you to suffer an injury during the course of the present studies. However, as the rugby sevens staff are following recognised training and testing procedures, participation in the present studies are very safe. You will not be exposed to any additional risk other than the normal risk of training which you are exposed to every day as an elite athlete.

Do I get a copy of my results?

If you wish to have a copy of your personal results, I am happy to send a report and a detailed explanation to you.

The expected benefits of the research

By participating in the present studies, you will help provide an insight into the physical and technical demands of rugby sevens preparation training camps, assisting in understanding how training camps are designed prior to tournaments. These results will allow for advancement in training programs and help to better prepare players for the physical, technical and tactical demands of competition.

Your participation is voluntary

Your participation in the present studies is voluntary. You may decide to not participate in the present studies or to withdraw from the studies at any time. You will not need to explain why

you have decided to not participate or withdraw and this will not have any effect on your relationship or your place in the team, with the researchers, or any of the institutions involved.

All results are confidential

The information that you provide to myself during the studies is strictly confidential. The list with names and codes will be kept in a safe place, and no information will be disclosed to third parties without your consent. Only the combined results of all participants who will remain anonymous will be published in reports and scientific publications and or presented as scientific conferences.

Questions/further information

If you have any questions about any part of the two studies, please contact the primary investigator Jesse Griffin from the Faculty of Health Sciences and Medicine at Bond University on 0431 766 309 or any of the other researchers listed on page 1.

The ethical conduct of this research

The present research abides by the National Statement on Ethical Conduct in Research Involving Humans. If you have any concerns with the ethical conduct of the research party, feel free to contact: Bond University Research Human Research Ethics Committee by phone on (07) 5595 4194 or email buhrec@bond.edu.au.

Appendix 2: Participant Consent Form

CONSENT FORM

BUHREC Protocol Number: RO1675

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(07) 5595 4487

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By signing below, I confirm that I have read and understood the information package and in particular have noted that:

- I understand that my involvement will include the completion of training camps as scheduled by the ARU;
- I have had all of my questions answered to my full satisfaction;
- I understand the risks involved;
- I understand there will be no direct benefit to me (that is, financial incentives etc.) from my participation in the present research;
- I understand that my participation in the present research is voluntary;
- I understand that if I have any additional questions I can contact Jesse Griffin or the other investigators;
- I understand that I am free to withdraw at any time, without comment or penalty;

- I understand that I can contact the Bond University Human Research Ethics Committee on (07) 5595 4194 or email buhrec@bond.edu.au, if I have any concerns about the ethical conduct of the project;
- I understand the present project will meet the National Statement on Ethical Conduct in Human Research (Privacy), at <http://www.nhmrc.gov.au/publications/synopses/e72syn.htm>; and,
- I agree to participate in the project.

Participant

Signature

Date

Jesse Griffin

Signature

Date

Appendix 3: Coding Template

Defence type	1	No defence
	2	Uncontested defence
	3	Contested defence
Pass type		
	1	Conventional
	2	Cut-out
	3	Dummy
	4	Switch
	5	Offload
Pass accuracy		
	1	Good
	2	Moderate
	3	Poor

Evasive move	1	Side-step
	2	Swerve
Line break		
	1	Yes
	2	No
Catching		
	1	Successful
	2	Unsuccessful

